Life History Studies of Anadromous Coregonid Fishes in Two Freshwater Lake Systems on the Tuktoyaktuk Peninsula, Northwest Territories

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by

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ABSTRACT

Bond, W.A., and R.N. Erickson. 1985. Life history studies of anadromous coregonid fishes in two freshwater lake systems on the Tuktoyaktuk Peninsula, Northwest Territories. Can. T ᵗ. Rep. Fish. Aquat. Sci. 1336: vii + 61 p.

The Tuktoyaktuk Peninsula is dotted with large numbers of interconnected tundra lakes which drain into the southern Beaufort Sea through small streams. Many of these streams support runs of anadromous coregonid fishes that utilize the lakes as feeding, rearing, and overwintering areas. Two such streams, Mayogiak Creek and Freshwater Creek, flow directly into Tuktoyaktuk Harbour where greatly increased vessel traffic and shoreline development have occurred in recent years. The purpose of the present study was to document and describe fish migrations within these two streams and to determine the significance of the two lake systems as fish habitat, especially for anadromous coregonids.

A preliminary investigation in 1981 verified the occurrence of substantial migrations of broad whitefish, Coregonus nasus (Pallas), lake whitefish, C. clupeaformis (Mitchill), and least cisco, C. sardinella (Valenciennes) in both streams. Work in 1982 concentrated on the Freshwater system in which the larger runs appeared to occur. This report highlights the results of the second year's work and attempts to draw together the results of both years.

A two-way fish counting fence was operated on Freshwater Creek from break-up, 21 June, to freeze-up, 12 October 1982. Upstream migrants totalled 100 178 broad whitefish, 9 684 lake whitefish, and 10 599 least cisco. Downstream figures for the same species were 105 149, 22 382, and 5 229, respectively. At the fence site data were collected describing the diel and seasonal timing of the migrations, the length-frequency distribution of the migrant populations, age and growth, sex and maturity, and food habits.

Most migrants were juvenile fish although the runs included mature spawners of all three coregonid species. Downstream migrations of broad whitefish, which began in July, included mature spawners which had overwintered within the watershed. Some broad whitefish and least cisco enter the lakes as young-of-the-year and may remain in the lakes for up to four years before returning to coastal habitats. On the other hand the runs of lake whitefish included few fish younger than age 4.

Brief surveys were conducted on nine lakes in the two watersheds to gather information on lake morphometry, water chemistry, benthic invertebrates, and zooplankton, as well as fish. Overwintering coregonids were captured in two lakes of the Freshwater Creek system while only northern pike, Esox lucius Linnaeus, were taken through the ice in the Mayogiak watershed.

Key words: migrations; anadromous species; whitefish, broad; whitefish, lake; cisco, least; Beaufort Sea; Mackenzie estuary; overwintering; feeding.

RESUME

Bond, W.A., and R.N. Erickson. 1985. Life history studies of anadromous coregonid fishes in two freshwater lake systems on the Tuktoyaktuk Peninsula, Northwest Territories. Can. Tech. Rep. Fish. Aquat. Sci. 1336: vii + 61 p.

La péninsule de Tuktoyaktuk est parsemée d'un grand nombre de lacs de toundra interreliés qui se déversent dans la partie sud de la mer de Beaufort par l'entremise de petites rivières. Un grand nombre de ces rivières assurent le passage de bancs de corégonides anadromes qui se nourrissent, se multiplient et hivernent dans les lacs. Deux de ces rivières, les ruisseaux Mayogiak et Freshwater, se déversent directement dans le Tuktoyaktuk Harbour, qui a connu au cours des dernières années une intensification du trafic maritime et un aménagement de plus en plus important de ses rives. L'étude présente vise à décrire la migration des poissons dans ces deux ruisseaux, déterminer l'importance, sous l'aspect habitat, des deux systèmes lacustres, particulièrement dans le cas des corégonides anadromes, et à établir une meilleure documentation à ce sujet.

C'est au cours d'une étude préliminaire menée en 1981 que l'on a pu vérifier la récurrence de migrations importantes du corégone tschir, Coregonus nasus (Pallas), du grand corégone, C. clupeaformis (Mitchill) et du cisco sardinelle, C. sardinella (Valenciennes) dans les deux cours d'eau. Le travail effectué en 1982 a surtout porté sur le système Freshwater où, apparemment, les migrations les plus grandes se produisaient. Ce rapport met en évidence les résultats de la deuxième année de travail et tente de lier les résultats des deux années.

De la débâcle du 21 juin 1982 à la prise des glaces du 12 octobre, on utilisa un barrage de dénombrement à deux sens des poissons sur le ruisseau Freshwater. On put dénombrer 100 178 corégones tschir, 9 684 grand corégones et 10 599 ciscos sardinelles en migration vers l'amont. Pour ces mêmes espèces, le dénombrement de poissons en migration vers l'aval était de 105 149, 22 382 et 5 229 respectivement. Au barrage même, des données furent recueillies décrivant les migrations par 24 heures et par saison, la répartition des populations migratoires par durée et par fréquence, l'âge et la grandeur, le sexe et la maturité ainsi que les habitudes alimentaires.

La majorité des poissons étaient jeunes, bien que les bancs comprenaient des poissons matures des trois espèces de corégonides. Les migrations vers aval du corégone tschir, qui avaient commencé en juillet, comprenaient des

poissons adultes prêts à frayer qui avaient hiverné dans le bassin hydrographique. Quelques corégones tschir et ciscos sardinelles pénètrent les lacs en tant que jeunes de l'année et peuvent y habiter quatre ans avant de retourner aux eaux côtières. D'autre part, les bancs de grands corégones comprenaient peu de poissons de moins de 4 ans.

De brèves études furent menées qui permirent de recueillir des renseignements sur la morphométrie, l'hydrochimie, les invertébrés benthiques, le zooplancton et les poissons sur neuf lacs des deux bassins hydrographiques. On a capturé des corégones hivernants dans deux lacs du système du ruisseau Freshwater, alors qu'on n'a capturé que des grands brochets à la pêche sur la glace dans le bassin hydrographique Mayogiak.

Mots-clés: migrations; corégones anadromes; corégone tschir; corégone, grand; cisco sardinelle; cycle evolutif; mer de Beaufort; estuaire du Mackenzie; hivernage; alimentation.

INTRODUCTION

The fish fauna of the southern Beaufort Sea coast is dominated during the summer months by anadromous coregonids, believed to be of Mackenzie River origin (Mann 1974; Craig and Mann 1974; Percy 1975; Kendel et al. 1975; Galbraith and Hunter 1975; Lawrence et al. 1984). Along the Tuktoyaktuk Peninsula (Fig. 1) the nearshore serves as a migration corridor, providing access to feeding, rearing, and overwintering sites located some distance from the Mackenzie itself. For some species these critical areas involve coastal bays and lagoons; this appears to be the case for Arctic cisco, Coregonus autumnalis (Pallas), and inconnu, Stenodus leucichthys (Guldenstadt). Recent studies, however, conducted by the Department of Fisheries and Oceans, indicate that certain species of anadromous coregonid fishes migrate out of coastal waters to enter tundra lakes located on the peninsula (Lawrence et al. 1984; K. Chang-Kue, personal communication). Such lakes may play a major role in the maintenance of the broad whitefish, Coregonus nasus (Pallas), lake whitefish, C. clupeaformis (Mitchill), and least cisco, C. sardinella (Valenciennes) populations of the Mackenzie River.

Despite the apparent remoteness of these populations, they are not immune from the effects of modern industrial progress. Recently, the search for hydrocarbons in the Beaufort Sea has produced a dramatic increase in the level of industrial activity near Tuktoyaktuk (Fig. 1), a trend which is expected to continue. Such activities, occurring in nearshore areas, pose an immediate threat to the progress of fish migrations along the coastal margin and have the potential to prohibit access to areas which may be critical to the life histories of these fish. The possibility of temperature and salinity changes in the Mackenzie River estuary as a result of major hydroelectric developments in the upper reaches of the watershed is also cause for concern. The combined effect of these activities on these important fish populations could be negative and long-term. If such negative impacts are to be minimized, it is necessary to define, more precisely than is presently possible, the details of what appear to be highly complex life history patterns. Such improved definition is the main objective of studies now being conducted in the Mackenzie Delta - Beaufort Sea area by the Department of Fisheries and Oceans.

The present study was initiated in 1981 to determine the significance as fish habitat of the tundra lake systems associated with Freshwater and Mayogiak creeks, two streams draining off the Tuktoyaktuk Peninsula into Tuktoyaktuk Harbour. During the first year of the study, field effort was divided between the two systems. While migrations were documented in both streams, the results of the first year's work (Bond and Erickson 1982) suggested a more significant role for Freshwater than for Mayogiak Creek. During the second year, therefore, the study focused more intensively on the former. This document presents the results of work done during 1982; it represents the final report for the project.

STUDY AREA

The study area involved two small watersheds situated between 69°15' and 69°30' N latitude and between 132°25' and 133°00' W longitude, just east of the Hamlet of Tuktoyaktuk on the Tuktoyaktuk Peninsula (Fig. 1). Mayogiak Creek watershed (Fig. 2), the smaller of the two, has a total drainage area of approximately 2 250 ha and is relatively simple, with only four lakes exceeding 25 ha in surface area. By contrast the Freshwater system (Fig. 3), lying immediately to the north and east, has a surface area of 9 050 ha and is more complex, with 29 lakes larger than 25 ha. In both cases, lake surface accounts for about 56% of the total drainage area. Both basins drain into the east side of Tuktoyaktuk Harbour through shallow streams which freeze to the bottom in winter.

According to Mackay (1963), the study area straddles two different subregions of the Pleistocene coastlands physiographic region. The Mayogiak watershed and the western half (Lakes 1, 2, and 8) of the Freshwater system lie within the undifferentiated coastlands subregion which is characterized by medium to large lakes, flats with pingos, and low hills. Most lake surfaces in this subregion are only 6-9 m above sea level. The eastern portion of the Freshwater system lies within the Involuted Hills subregion, an area of greater relief in which lake surfaces range from 15-38 m above sea level. The sediments of this region, mostly medium to fine sand, are underlain by massive sheets of ground ice and covered by tundra vegetation, scrub willows, and ground birch.

The climatology of the area has been reviewed in detail by Burns (1973). Extreme temperatures at Tuktoyaktuk can vary from about 30°C to -50°C. Daily mean temperature is highest in July (10°C) and lowest in January and February (-30°C). The mean date of last frost is 30 June while first frost usually occurs about 20 August. During the 1982 study period, maximum daily air temperatures at Tuktoyaktuk ranged from 28°C to -25°C (Fig. 4). Mean annual precipitation is less than 25 cm, most of which falls as rain during July and August.

At this latitude there is continuous sunshine from approximately 21 May to 21 July (Fig. 5). Freeze-up generally occurs in September or October with break-up occurring in late June. Lakes tend to remain ice-covered for approximately 250 days a year.

Mayogiak and Freshwater creeks, like other streams on the Tuktoyaktuk Peninsula, begin to flow in mid-June, several weeks before the landfast sea ice breaks up. This fact may be of major importance to migratory coregonids considering the annual salinity patterns that are observed along the Tuktoyaktuk coast. These salinity features have been reviewed by Barber (1968), Milne and Smiley (1976), and Fraker et al. (1979). Under the cover of sea ice, fresh water from the Mackenzie River accumulates in inshore areas of Kugmallit Bay, gradually displacing the brackish water that occupies those sites during the summer. As winter proceeds, the plume extends further and further along the

coast of the Tuktoyaktuk Peninsula, creating a freshwater corridor that may, in some years, reach as far as McKinley Bay (Fig. 1). After break-up, this freshwater zone disintegrates under the influence of wind action, resulting in an increase in the inshore salinity.

MATERIALS AND METHODS

COUNTING FENCE OPERATIONS

Fish movements between Tuktoyaktuk Harbour and the tundra lakes of the two watersheds were monitored using two-way counting fences. The installation and operation of such structures in both Mayogiak and Freshwater creeks in 1981 resulted in the documentation of coregonid migrations in both streams although operational difficulties precluded a complete assessment in either case (Bond and Erickson 1982). In 1982, a fence was operated only in Freshwater Creek.

The 1982 counting fence on Freshwater Creek was situated a short distance upstream of the 1981 site, approximately 8.5 km above Tuktoyaktuk Harbour and about 0.5 km below the stream's outfall from the lowest major lake in the system (Fig. 3). As in the previous year, traps and fence wings were constructed of 2.54 cm welded wire fabric covered with 0.63 cm plastic mesh to prevent gilling of smaller fish.

Ice-out at the Freshwater Creek fence site occurred at 2030 h on 20 June 1982, eight days later than in 1981. Fence construction began soon after ice-out and was completed on 22 June. Monitoring of upstream movements began at 2300 h on 21 June and continued until 1 October. Downstream monitoring was conducted from 4 July until 12 October when the imminence of freeze-up (Fig. 4) forced the removal of the fence. Except for a brief period on 30 June, the fence was operated on a 24 hour per day basis, seven days a week throughout the study period. Traps were attended continuously during periods of heavy migration and were checked hourly or every two hours as required at other times. Water temperature was recorded regularly using a pocket thermometer.

Trapped fish were dipnetted from the holding boxes, enumerated by species, and passed through the fence in the direction in which they were travelling. The only exception to this procedure occurred during the heavy upstream run of the first week of July. At that time the adjustable rear door of the upsteam trap was opened sufficiently to permit free passage of fish while counts and identifications were made by an observer stationed atop the trap. This process was facilitated by painting the trap floor white and placing white sand bags on the stream bed upstream of the trap, thus providing a good background against which to view the fish.

Fork lengths (±1.0 mm) were recorded for as many fish as possible each day from both the upstream and downstream runs. A few fish of each species, selected to cover the entire length range present in the migrations, were sacrificed for a more detailed analysis as described below.

Problems associated with fence operations

Several problems were encountered during the 1981 phase of the study which reduced the efficiency of the fence operations and resulted in serious data gaps (Bond and Erickson 1982). Most of these problems were overcome in 1982, permitting a more complete and reliable assessment.

As in 1981, plant material (mainly duckweed, Lemna trisulca), originating in the lakes and drifting downstream, was a constant problem. Such material can quickly clog a fence and must be cleaned from the structure regularly to prevent washouts. In anticipation of this problem, the 1982 fence was moved upstream of the 1981 site, to a location where the stream was wider, shallower, and with less current. Additionally, the use of longer fence wings, deployed at a steeper angle, reduced the effect of current on the structure. The fence was examined regularly for signs of weakness and repaired as required.

Whereas, in 1981, the combined effect of plant material and strong current necessitated the removal and re-installation of the fence on several occasions, leading to considerable down time, only one move was required in 1982. This occurred as a result of damage inflicted by the downstream movement of massive sheets of ice. The fence was removed from the stream at 0630 h on 30 June, but was quickly reconstructed and was fully operational again by 1700 h the same day. No other down time was recorded during 1982.

Chang-Kue (personal communication) reported a high degree of confidence in his ability to distinguish between broad whitefish, lake whitefish, and least cisco in Kukjuktuk Creek by viewing the fish from above as they passed through the upstream trap. This method was considered less reliable, however, at Freshwater Creek in 1981 because of turbulence in the trap (Bond and Erickson 1982). This problem was overcome in 1982 by placing the traps in shallower water with less current, and by providing a white background against which to view the fish.

The problem of upstream fish being carried into the downstream trap was also minimized during the 1982 study. This problem often occurs when large upstream and downstream runs occur simultaneously, and seems to be exacerbated by handling or by prolonged retention of fish in the traps. Such fish, when passed through the trap, tend to hold immediately upstream, probably to regain lost strength. They are often swept into the downstream trap by the current, or pushed in by downstream migrants. By locating the upstream trap in an area of reduced current, by minimizing the retention time within the trap, and by permitting free passage at times of heavy migration, this problem was largely overcome.

In late August and September, it became apparent that some small broad whitefish and least cisco were having difficulty locating the entrance to the upstream trap and were simply holding on the downstream side of the fence. To facilitate their passage, the area downstream of

the fence was swept on six occasions with a small mesh seine, thus forcing these small fish into the trap. Such fish were considered to be upstream migrants and were included in the daily counts.

LAKE SURVEYS

Nine lakes were surveyed during the study, four in the Mayogiak watershed and five in the Freshwater system. Three lakes in each watershed were sampled in 1981 (Bond and Erickson 1982). During summer, 1982, the three Freshwater lakes were revisited, and the study was extended to include Mayogiak Lake 5 and Freshwater lakes 6 and 8. These surveys provided information on lake morphometry, water chemistry, zooplankton, macrobenthos, and fish. Three lakes were visited between 7 May and 9 June 1982 in an effort to obtain evidence of fish overwintering.

Bathymetry and morphometry

Outline maps for the lakes to be sounded were prepared by enlargement of tracings taken from 1:50 000 scale topographic maps (Canada Department of Energy, Mines and Resources). Soundings were made of six lakes in 1981 (Bond and Erickson 1982) and two lakes in 1982. Graphical depth profiles were produced along predetermined transects using a Furuno FG200A Mk. 3 battery-powered recording echo sounder. Transects were run at constant speed using a 5 m aluminum boat powered by a 20 HP engine. The data obtained were used to construct bathymetric maps of each lake.

Surface areas and shoreline lengths for each lake were measured directly from the outline maps using either a Hewlett-Packard 9100B calculator coupled with a Hewlett-Packard 9107A digitizer (precision of ±1.0%), or a Hewlett-Packard 9830A calculator with a 9864A digitizer.

Franzin and McFarlane (1976) determined that the above procedures yielded an estimated error of ±10% on the volume calculations. In the present study, however, the error on the volume calculations was considerably greater than this because of the inherent imprecision of the sounder in estimating depths of less than 3 m, and because of technical problems related to the stylus and transducer. A field test of the sounder in 1982 showed the machine to underestimate depth by 50% at 1 m, 25% at 2 m, 25% at 4 m, and 10% at 9 m. These figures, which would lead to an underestimation of volume, were not taken into account in our calculations.

Morphometric parameters for each lake sounded were calculated according to the procedures described by Hutchinson (1957).

At each lake surveyed in 1981, a general description of shoreline vegetation was obtained and the nature of the substrate near the water's edge was described according to the classification of Cowardin et al. (1979): i.e., mud (clay-silt) - particles less than 0.074 mm in diameter; sand - 0.074 to 2 mm; gravel - 2 mm to 7.6 cm; cobble - 7.6 to 25.4 cm; stone - 25.4 to 61.0 cm (Bond and Erickson 1982). Similar analyses were not performed in 1982.

Physico-chemical

Physico-chemical analyses were not performed in a uniform way throughout the study. In 1981, water temperature profiles were done at the deepest point in each lake using a model 33 YSI meter, and the secchi disc transparency was determined. Water samples were taken using a 2 L Van Dorn water bottle. Samples for analysis of dissolved oxygen were preserved in the field. Dissolved oxygen, pH, and conductivity were determined within twenty-four hours at the field laboratory in Tuktoyaktuk (Bond and Erickson 1982). Similar procedures were followed for most lakes surveyed during open water in 1982 only with respect to water temperature and transparency.

During the 1982 winter surveys, ice thickness and depth of water under the ice were recorded and dissolved oxygen was determined in the field using a Hach kit. One litre water samples from each lake were flown to the Analytical Chemistry Unit of the Freshwater Institute where analyses were performed for total dissolved phosphorus, total dissolved nitrogen, chlorophyll-a, soluble reactive silica, total suspended solids, suspended phosphorus, suspended nitrogen, pH, suspended carbon, and dissolved organic carbon. A few of these parameters were also estimated from the 1982 open water period.

Biological

Benthos: The benthic macroinvertebrate fauna of the lakes was sampled by means of an improved Ekman-type grab (Burton and Flannagan 1973). One to eight grab samples were acquired from the various lakes, placed in plastic bags in the field, and preserved in 10% formalin. In 1982 a qualitative evaluation of substrate type as either predominantly organic or predominantly sand was made for each grab sample. Preserved samples were later washed through a 505 µm Nitex screen, sorted, identified to the lowest possible taxon, and counted. Identifications were made using keys provided by Edmondson (1959), Merritt and Cummins (1978), Usinger (1971), and Pennak (1978).

Zooplankton: A small (20 cm opening) Wisconsin-style plankton net constructed of 73 µm Nitex was used to sample the zooplankton of the lakes. In 1981 two vertical hauls were taken near the deepest point in the lake. In 1982, horizontal hauls of three minutes duration were taken in addition to vertical hauls. Plankton samples were fixed in 5% formalin. A qualitative analysis of the samples was conducted to identify the zooplankton species present.

Fish: Fish in the lakes were sampled mainly by gillnets with seines being used on only a few occasions. The gillnets used were Swedish survey nets, 60 m long by 1.8 m deep and consisted of equal lengths of 10, 19, 33, 45, 55, and 60 mm multifilament nylon mesh (bar measure). These nets were set on the bottom, usually at two locations in each lake, for periods of 2 to 24 hours. Under-ice sets were made in Mayogiak Lake 5 and Freshwater Lakes 3 and 8 between 30 May and 9 June 1982 in an attempt to locate overwintering fish.

Upon lifting the nets, fish were separated according to mesh size and subjected to a complete biological analysis. In each case fork length (±1.0 mm) and body weight (usually ±10 g) were recorded. For coregonids, scales, saggital otoliths, and left pectoral fins were retained for age determination. A qualitative description of the degree of gonadal development was performed according to the following scale.

Female	Male	
1	6	Immature
2	7	Maturing
3	8	Mature
4	9	Ripe
5	10	Spent
0		Sex Indistinguishable

This technique was also applied to migrant fish captured at the fence site.

Although widely used, such subjective analyses, based on gross examination of gonads, often provide unreliable information on maturity stage in whitefish (Healey 1975; Bond 1982). Failure to identify spawners-of-the-year occurs frequently in the early part of the year and more often in males than in females. A more objective assessment, such as is provided by the gonadosomatic index (GSI), removes much of the uncertainty in this regard and provides a sounder basis for comparisons between studies.

To this end the gonads were removed from some migrants and weighed fresh (±1.0 g). The data on body and gonad weight were then used to determine the gonadosomatic index by the formula

$$GSI = \frac{\text{Gonad Weight}}{\text{Fish Round Weight}} \times 100$$

The stomach of each fish was removed and either examined on site or preserved in 10% formalin for more detailed laboratory analysis. Laboratory analysis of preserved stomach contents was conducted using the volumetric point system described by Thompson (1959). The amount of food present in each stomach was assigned a point value between 0 and 20 based on its volume. The value 0 was given only when the stomach contained no organic material while the value 20 indicated a gorged state. After separating the various food items according to taxon, the assigned point value for each stomach was subdivided among them according to their estimated volume. Mollusc shells were included in the volume estimation. Because no partial food points were assigned, this system tends to overestimate the contribution of small animals occurring in small numbers. The method is rapid, however, and appears to provide an acceptable description of the stomach contents. Results of the stomach content analysis were also expressed in terms of numbers of food organisms present and their frequency of occurrence.

Broad whitefish, lake whitefish, and least cisco were aged using scales. Several scales from each fish were cleaned in a sodium hypochlorite solution (Javex) and mounted between two glass slides; the annuli were counted on the image produced by a microprojector. As has been reported by many authors, determination of the first annulus was sometimes difficult, especially for broad whitefish. We attempted to solve this problem by examining closely the scales of a large number of age 0, 1, 2, and 3 broad whitefish that had been captured at various times throughout the year. The assigned scale age was equal to the number of completed annuli except for fish captured in June and early July which had not yet laid down their new annulus. In such cases the fish were credited with an additional annulus.

Although scales are a favoured method for aging many fish species, the results obtained by the scale method have been called into question in recent years (Ovchynnyk 1965; Beamish and Harvey 1969; Sych 1971; Aass 1972; Mills and Beamish 1980). In cases where scale ages have been compared with those determined from other body structures, such as otoliths or fin rays, the scale ages have often been found to underestimate age, especially in the older age groups. Studies comparing the results of various aging techniques for the anadromous coregonid fishes of the southern Beaufort Sea area are few. Where comparisons have been made, it has been observed that there can be major discrepancies between results obtained through different aging techniques. Mann (1974) compared scale ages and otolith ages for least cisco and reported that, while results agreed closely among younger age groups, scales tended to underestimate the age of older fish. Craig and Mann (1974) reported similar results in the case of Arctic cisco.

Because knowledge of the age structure of a fish population is fundamental to its proper management, there is an urgent need to establish the usefulness and reliability of various aging techniques for the fishes of the southern Beaufort Sea. During the present study an attempt was made to compare the results obtained from scales, otoliths, and fin rays for broad whitefish, lake whitefish, and least cisco. Preliminary results of this study were presented by Bond and Erickson (1982). Some additional results are provided in this report.

Otoliths from small fish were ground by hand on a carborundum and cleared in a 3:1 mixture of benzyl-benzoate and methyl salicylate. These were viewed under a stereomicroscope using reflected light against a black background. Otoliths of larger fish were embedded in a clear epoxy and sectioned using a Bronwill high speed thin-sectioning machine. Three to four transverse sections (approx. 0.3 mm thick) were taken through the nucleus of the otolith. The sections were mounted in "Diatex" on glass slides and viewed at various magnifications under a compound microscope.

Pectoral fins were also embedded in epoxy and sectioned (0.3 mm) on the thin-sectioning machine. Three to four sections were taken perpendicular to the rays, beginning about 3 mm from the base of the fin. These were then mounted in "Diatex" on glass slides and viewed using a compound microscope.

Weight-length relationships for the anadromous coregonids were described by the power equation:

$\log_{10}W = a + b (\log_{10}L)$; SDb =

where W = weight (g)
L = fork length (mm)
a = y-intercept
b = slope of the regression line
SDb = standard deviation of b.

Coefficients of condition (K) were computed for individual fish from:

$$K = (Wx10^5)/L^3$$

where W = weight (g)
L = fork length (mm)

RESULTS AND DISCUSSION

LAKES OF THE FRESHWATER AND MAYOGIAK WATERSHEDS

Between July, 1981, and September, 1982, certain physical, chemical, and biological data were gathered from nine lakes in the two watersheds. Some of these data have already been presented (Bond and Erickson 1982) and do not reappear in this report. Others, where considered appropriate, are shown again either on their own or in combination with data gathered in 1982.

Morphometry

Bathymetric maps for three lakes in each watershed were presented in Bond and Erickson (1982). Bathymetric maps for Mayogiak Lake 5 (Fig. 6) and Freshwater Lake 8 (Fig. 7) were drawn from 1982 data. The morphometric features of these lakes are presented in Table 1.

As Table 1 indicates, the four Mayogiak lakes surveyed ranged from 23.6 to 440.0 ha in surface area and from 0.2 to 1.1 m in mean depth. Lake 5, with a maximum depth of 4 m and an estimated volume of $4.8 \times 10^6 m^3$, is the largest lake in the watershed and possibly the only one capable of providing overwintering habitat for fish. Although a maximum depth of 3 m was recorded by hand sounding in Lake 3, most of this lake appears to be less than 2 m deep.

Among the lakes surveyed in the Freshwater Creek watershed, surface areas varied from 180.7 to 1235.5 ha and mean depths from 0.6 to 1.5 m. Lakes 1 and 2 are large lakes (560.2 and 817.3 ha, respectively) which seldom exceed 1.5 m in depth. On the other hand, both Lake 3 and Lake 8 contain deep holes. Maximum depth recorded in Lake 3 was 5 m while 8 m of water was found in the southwest bay of Lake 8. Deep water was also found in the central and northern basins of this large lake which has an estimated volume of $1.9 \times 10^7 m^3$. In terms of total surface area, 12.6% of Lake 8 is deeper than 3 m (156 ha).

Most of the lakes surveyed during the study had very regular, willow-lined shorelines with development factors between 1.3 and 1.7. The outlines of both Mayogiak Lake 5 and Freshwater Lake 8 were considerably more irregular, with development factors of 2.4 and 2.6, respectively. The substrate in most nearshore areas consisted of silts, clean sand, or cobbles.

Physical and chemical

Lakes of the Mayogiak and Freshwater systems became ice-free in late June in both years of the study. Freeze-up occurred in October. Ice thickness, measured for three lakes on 12-14 May 1982, ranged from 1.6 to 1.8 m (Table 2).

The water temperature in the lakes, which is presumed to remain near 0°C throughout the winter, can increase rapidly after break-up, depending on air temperature and wind. Summer maxima are achieved in late July but the lakes cool off in August. July temperatures recorded in this study were 15.0 to 18.0°C in Mayogiak lakes and 17.0 to 18.5°C in Freshwater lakes. August temperatures varied from 9.4 to 11.5°C. (Table 2).

Secchi disc transparency, a measure of light penetration, ranged from 0.7 to 1.9 m in Mayogiak lakes and from 1.3 to 3.8 m in Freshwater lakes. Specific conductance varied in general from 144 to 209 $\mu S \cdot cm^{-1}$ although a range of 763 to 781 was determined for Mayogiak Lake 1. Conductivity was not measured during the winter.

Summer pH values ranged from 7.35 to 8.80 while late winter values varied from 6.90 to 6.96. Dissolved oxygen readings during the open water period ranged from 8.9 to 12.0 $mg \cdot L^{-1}$, indicating saturation levels in most lakes. Oxygen readings in late winter (30 May to 8 June 1982) were 2.0 $mg \cdot L^{-1}$ and 7.0 $mg \cdot L^{-1}$ in Freshwater lakes 3 and 8, respectively, and 5.0 $mg \cdot L^{-1}$ in Mayogiak Lake 5 (Table 2). Assuming a water temperature of 0.5°C, these readings represent approximate saturation levels of 15%, 50%, and 35%, respectively.

No evidence of summer stratification was found in any of the lakes examined as temperature, pH, conductivity, and dissolved oxygen were generally constant throughout the water column (Bond and Erickson 1982).

Biological

Zooplankton: Although a quantitative assessment was not conducted, Copepods appeared to dominate the plankton community of the lakes in both watersheds. Copepoda identified included four species of calanoids, two species of cyclopoids and one species of harpacticoids (one immature specimen). At least seven species of Cladocera were identified from the samples (Table 3).

Several plankton species were identified from only one of the watersheds. For example, the copepod, Cyclops vernalis, and the cladocerans, Ceriodaphnia quadrangula, Chydorus sphaericus, and Heterocope septentrionalis, were identified from the Mayogiak but not from the Freshwater samples. The Calanoid copepod, Epischura lacustris, and the cladocerans, Eubosmina longispina and Holopedium gibberum were found only in the Freshwater samples. Little significance is attached to these differences because of the limited sampling effort involved in the study. It is most likely that further sampling and a more rigorous analysis would expand the species list in all of the lakes. It should be

noted that plankton samples were obtained from Freshwater lakes 1 and 2 in both years of the study while all other lakes were sampled only once; several species were encountered in 1982 that were not identified in 1981.

Benthos: Twenty-eight taxa of benthic organisms were identified from the lakes of the two systems (Table A1.1). Included on the list are a few taxa, e.g. Lepidurus sp., that were not found in dredge samples but appeared in the stomach contents of fish captured in the lakes. The greater number of taxa identified from the Freshwater system (27) is thought to reflect the greater sampling and identification effort applied there than in the Mayogiak system.

The benthic fauna of the lakes of both watersheds was dominated numerically by Mollusca, Diptera larvae, Oligochaeta, and Amphipoda (Tables 4 and 5). Only in the 1981 sample from Freshwater Lake 1 (78%) did these four taxa comprise less than 98% of the benthos. The pelecypod mollusc, Sphaerium sp., was the most abundant form encountered in most lakes, achieving densities of $1001 \cdot m^{-2}$ and $1077 \cdot m^{-2}$ in the 1982 samples from Freshwater lakes 1 and 2, respectively. Excluding Mayogiak Lake 1, densities for the gastropod, Valvata sincera helicoidea, varied from $11 \cdot m^{-2}$ to $441 \cdot m^{-2}$. This species was the most abundant form taken from Freshwater Lakes 2 and 3 in 1981. Lymnaea palustris was found only in Freshwater lakes 3 ($11 \cdot m^{-2}$) and 8 ($27 \cdot m^{-2}$). Oligochaete densities varied from $43 \cdot m^{-2}$ in Mayogiak lakes 1 and 3 to $754 \cdot m^{-2}$ in the 1982 sample from Freshwater Lake 1. The benthos contained few Diptera other than Chironomidae. The chironomid fauna in the lakes included seven genera of Chironominae, of which Chironomus sp., Stictochironomus sp., and Phaenopsectra sp. were the most common. Densities for Gammarus lacustris were similar for most of the lakes ($11\text{-}43 \cdot m^{-2}$) but higher values were recorded in Freshwater lakes 3 ($65 \cdot m^{-2}$) and 8 ($102 \cdot m^{-2}$).

Excluding Mayogiak Lake 1, total benthos densities ranged from 20 to $2411 \cdot m^{-2}$ with both extremes being recorded for Freshwater Lake 1. The effect of substrate on the benthos is demonstrated in Table 6 which indicates that, overall, the density of benthic organisms inhabiting organic substrates was triple that found on sand. The difference was most pronounced for oligochaetes where the mean density on organic substrates was six times that for sand.

Fish: Anadromous coregonids dominated gillnet catches in the lakes of the Mayogiak (90%) and Freshwater (80%) drainages (Tables 7 and 8). In both systems broad whitefish was the most abundant species captured. Broad whitefish from Mayogiak lakes ranged in fork length from 151 to 353 mm (Fig. 8) although only two fish exceeded 300 mm. Few broad whitefish larger than 300 mm were encountered at the Mayogiak Creek counting fence in 1981 (Bond and Erickson 1982). By contrast, broad whitefish captured in Freshwater lakes ranged from 99 to 573 mm in length with 83% of the catch being longer than 300 mm (Fig. 8).

Northern pike, Esox lucius Linnaeus, were captured only from Lake 5 of the Mayogiak system although they were taken during the 1981 fence operation and in hoopnets set in the stream between Lakes 1 and 2 (Bond and Erickson 1982). Pike were taken in Lakes 3, 6, and 8 of the Freshwater drainage and were the most abundant species gillnetted from Lake 8 where they comprised 42% of the total catch (Table 8).

Burbot, Lota lota (Linnaeus) and lake trout, Salvelinus namaycush (Walbaum), apparently occur in the Freshwater but not in the Mayogiak system. Within the Freshwater drainage, burbot were gillnetted only in Lake 8 but were also captured at the counting fence. Lake trout (n=7) were taken at the fence but were not captured in gillnets.

The only other fish species known to inhabit the lakes of these watersheds are ninespine stickleback, Pungitius pungitius (Linnaeus), (both systems) and pond smelt, Hypomesus olidus (Pallas) (Freshwater system).

Gillnetting through the ice in late May and early June, 1982, before the streams of the area had begun to flow, provided evidence of fish overwintering in several lakes. Only pike (n=4) were captured through the ice in Mayogiak Lake 5 and only broad whitefish (n=6) were taken in Freshwater Lake 3. Five species, however, including broad whitefish, lake whitefish, northern pike, least cisco, and burbot were found overwintering within the northern basin of Freshwater Lake 8. Neither the central basin nor the deep southwest bay of this lake were tested but both would appear, on the basis of depth, to be capable of providing overwintering habitat.

FISH LIFE HISTORIES

Summary

The 1982 counting fence on Freshwater Creek was run continuously (except for a 12-hour period on 30 June) from shortly after ice-out until just prior to freeze-up. The upstream trap was operated from 21 June to 1 October, producing 120 706 fish, of which 83.0% were broad whitefish, 8.8% least cisco, and 8.0% lake whitefish. Upstream migrations were heaviest in late June and early July, as the fish moved rapidly out of coastal waters. These three anadromous species also dominated the downstream runs, contributing 79.1%, 3.9%, and 16.8% respectively. A total of 132 940 fish were taken in the downstream trap between 1 July and 12 October. In addition to the coregonids, small numbers of northern pike, lake trout, ninespine stickleback, pond smelt, and burbot were also captured at the counting fence (Table 9).

The following sections provide detailed descriptions of the upstream and downstream migrations for the three coregonid species as well as biological evaluations of the migrant populations.

Broad whitefish

Timing of migrations: A total of 100 178 broad whitefish were counted through the up-

stream trap during the study. Upstream movement past the fence site began immediately after ice-out on 20 June and was most intense between 21 June and 6 July when 59% of the total run occurred. Maximum daily water temperature increased from 3° to 10°C during this period. Following 6 July, upstream movements continued but at a much reduced rate, with little activity occurring after 31 August (Fig. 9, Table A2.1).

The progress of the upstream migration was interrupted between 27 June and 2 July (Fig. 9), apparently as a result of a combination of weather-related events. Warm, sunny weather occurred during the first week of the run, culminating with maximum air temperatures of 27.6° and 28.2°C on 27 and 28 June, respectively. The days following were cloudy and cooler, and a severe thunderstorm occurred on the night of 1-2 July. Throughout this period fence operations were hindered by the downstream movement of large quantities of ice which eventually forced removal and reconstruction of the fence on 30 June. The instream activities of the field crew at this time may have deterred the fish to some extent, although few were seen in the stream during the reconstruction phase and only 37 broad whitefish were counted at the upstream trap on the night of 1-2 July.

Downstream migrants began to appear at the fence site on 29 June when four large broad whitefish passed downstream through the upstream trap. Several others were observed over the next few days, some of which were dip-netted and released downstream of the fence. These fish were considerably larger than any that had been observed moving upstream. Although a more concerted downstream run began on 4 July, downstream activity remained light until near the end of August when a major migration commenced (Fig. 9). Between 27 August and 6 October, more than 91 000 broad whitefish were counted at the downstream trap. This run occurred in three waves, peaking on 28 September. Maximum daily water temperature decreased rapidly throughout most of this period, reaching 0°C by 4 October.

Broad whitefish demonstrated a strong diel periodicity in both the upstream and downstream runs (Fig. 10). In both cases, activity was concentrated in the late evening and early morning hours, with a peak just before midnight. In the case of the upstream run, therefore, most activity occurred at the time of lowest light intensity during the period of continuous daylight. By contrast, most downstream movement took place in darkness.

Length-frequency distribution: Fork lengths were recorded for 3 978 broad whitefish from the upstream migration and for 8 523 downstream migrants. The length-frequency distributions obtained from the measured samples (Fig. 11 and 12) were applied to the total counts recorded in each of the indicated time periods to produce overall length-frequency descriptions of the upstream and downstream migrations (Fig. 13).

Upstream migrants ranged in fork length from 51 to 546 mm. Although most fish (54%) exceeded 225 mm, the length-frequency distribution (Fig. 13) was distinctly bimodal with strong modes occurring between 50 and 99 mm and in the 225-249 mm length interval. Fish in the 100-224 mm range accounted for only 24% of the total upstream migration, a situation similar to that observed in Mayogiak Creek in 1981 (Bond and Erickson 1982). The downstream migration involved broad whitefish with fork lengths ranging from 68 to 634 mm. Most downstream migrants (74%) were between 225 and 474 mm and, significantly, only 2% were less than 225 mm in length (Fig. 13).

Although approximately equal numbers of broad whitefish were counted in the upstream and downstream migrations, it is evident that, to a large extent, different fish were involved in the two runs. As Fig. 13 indicates, the upstream migration included approximately 41 000 small whitefish (<225 mm) that did not return downstream in 1982. By contrast, the downstream run of larger fish (>225 mm) exceeded the upstream run by approximately 47 000.

In both the upstream and downstream runs the largest broad whitefish tended to migrate first, followed by the smaller members of the population. This tendency was especially evident among upstream migrants where the modal length interval decreased from 450-474 mm on 21-22 June to 125-149 mm on 13-21 July (Fig. 11). After 26 July, most upstream migrants (70%) were shorter than 100 mm.

The steady downstream movement observed between 29 June and 26 August involved mainly fish in the 350-499 mm range (80%). The modal length interval during this period was 450-474 mm and 44% of the fish were larger than 450 mm. The large downstream migration in September involved an increasing proportion of smaller individuals as the modal length interval, which was 350-374 mm during 2-15 September, decreased to 300-324 mm by 16-21 September, to 250-274 mm by 26-28 September, and to 225-249 mm by early October (Fig. 12).

Age and growth features: Scale ages were determined for 361 broad whitefish captured throughout the 1982 fence operation at Freshwater Creek. An effort was made to ensure that the fish retained for aging represented the entire size range encountered in the runs. Scale age and otolith age were compared for 186 individuals while scale age and fin-ray age were compared in 79 cases (Fig. 14). The results suggest that scales may underestimate age among older fish, and some very large discrepancies were observed between scale age and otolith age in individuals older than 13 years. In one extreme case a fish (634 mm) was assigned a scale age of 14 years and an otolith age of 35.

Although agreement (±1 year) was 81% for both the scale:otolith and scale:fin-ray comparisons, the results are considered to be preliminary and inconclusive. Considerable difficulty was encountered with all three structures in determining the first annulus and in distinguishing the outer annuli in older fish.

In our study, the first annulus on broad whitefish scales appeared to form in late July and was completed by 31 July in 88% of the yearlings examined (n=24; 79-174 mm). This was usually a classic annulus, involving crowding of

circuli and cutting-over at the start of the second year's growth. It was noted, however, that an extraneous mark sometimes occurred inside the first annulus which, in older fish, could be misinterpreted as an annulus. This mark was often observed on the scales of young-of-the-year whitefish captured in September, and appeared to result from the deposition of an extra circulus between circuli 5 and 8. The extra circulus produced a crowding effect, giving the impression of an annulus although no cutting-over was involved and the feature did not always appear on all of the scales. The deposition of a "supplementary annulus" or "fingerling ring" during the first year of life has also been reported for coregonids in the Soviet Union (Reshetnikov 1966; Redkozubov 1968).

Age and growth features for broad whitefish captured during the 1982 migrations in Freshwater Creek are summarized in Table 10 and Fig. 15. Table 11 presents length-frequency distributions for fish of each age group. Overall, scale ages ranged from 0+ to 18 years although distinct differences were apparent between the age structure of the upstream and downstream runs.

Considering length as an indication of age, Fig. 13 suggests clearly that the majority of upstream migrants were younger than age 7 and that few exceeded age 10. The most abundant age groups in the upstream run were 0+ (1982 year class) and 3 to 4. In comparison with the upstream run, the downstream migration involved few fish younger than age 3 to 4 and a considerably larger number of fish in the 5 to 12 year range.

The growth rate of broad whitefish in Freshwater Creek (Fig. 15) is similar to that observed for this species by other studies in this area (Hatfield et al. 1972; de Graaf and Machniak 1977; Bond 1982).

Length-weight relationship and condition: The overall mathematical relationship between fork length and body weight for broad whitefish from Freshwater Creek (n=719, range 56-634 mm) is described by the equation:

$\log_{10}W = 3.2646\ (\log_{10}L)-5.5757$; SDb = 0.0111

Separate calculations for male and female broad whitefish from the upstream and downstream runs produced slightly different values for slopes and intercepts (Table 12). Analysis of covariance, however, indicated no significant difference overall ($P>0.05$) between the slopes ($F=0.5422$; 336df) or elevations ($F=0.3466$; 337df) of the length-weight regressions for males and females. Length-frequency distributions for broad whitefish used in the regression analysis are shown in Fig. 16.

The coefficient of condition or condition factor (K) is often used to describe the plumpness or well-being of a fish. It can vary according to sex, season, or place of capture.

In the present study, individual K values were used to calculate mean values for male and female broad whitefish within each of three time periods, i.e., upstream June, downstream July, and downstream September. Fish were further sub-divided as shorter or longer than 425 mm in order to isolate the effect of sexual development on the value of K. In all cases, t-tests indicated no significant difference in K between male and female broad whitefish within size groups and within time periods and, therefore, the data were pooled (Table 13).

As Table 13 indicates, the mean condition factor for broad whitefish less than 425 mm was lowest among June upstream fish (1.2077) and highest for September downstream migrants (1.3092). An intermediate value (1.2530) was obtained for fish moving downstream in July. The differences between the means for the three time periods were all statistically significant ($P<0.01$).

Among broad whitefish greater than 425 mm in fork length, the highest mean K (1.5358) was observed for July downstream migrants (Table 13). This segment of the run is known to include a considerable number of mature spawners which overwintered in lakes of the Freshwater Creek drainage system. By contrast, upstream July fish (1.3546) and downstream September fish (1.4809) are thought to be mainly non-spawners.

The high K factors for July downstream migrants indicate that excellent overwintering conditions exist within the Freshwater lake system. Certain individuals, however, did not overwinter well and were in obviously poor condition when they passed the downstream trap. These "slinks" (n=5), which were excluded from the forgoing calculations, had fork lengths ranging from 450 to 570 mm and K values between 0.9744 and 1.1083 (mean = 1.0406).

When condition factors are considered within age groups (Table 10), it is noted that mean K values increase gradually through age 9. A large jump occurs, however, between age 9 (1.27) and age 10 (1.52), reflecting the appearance of mature spawners in the samples.

Sexual maturity: Broad whitefish in the southern Beaufort Sea usually achieve first maturity at age 7 or 8 (Kogl 1972; de Graaf and Machniak 1977; Bond 1982). In Tuktoyaktuk Harbour, the smallest mature individuals were in the 420-450 mm size range (Bond 1982), although catches made during spawning migrations in the Mackenzie River suggest that most spawners exceed 450 mm (Stein et al. 1973; Chang-Kue and Jessop, unpublished data).

Observations at Mayogiak and Freshwater creeks in 1981 detected no mature broad whitefish in the runs and the available data showed few individuals larger than 450 mm (Bond and Erickson 1982). The more complete results of the 1982 study tend to support the 1981 findings that the majority of migrant broad whitefish in Freshwater Creek were juveniles.

Gonadal examinations detected no mature fish during the 1982 upstream migration. Furthermore, the length-frequency distribution (Fig. 13) suggests the presence of few spawners in this phase of the run. Of the largest

(oldest) upstream migrants, which passed the fence site during the last 10 days of June (n=29 552), 86.3% were smaller than 450 mm while only 0.2% were larger than 499 mm. Similarly, in the major downstream run between 27 August and 28 September (n=77 018), 87.1% of the migrants were smaller than 450 mm while only 0.6% exceeded 499 mm.

In comparison, the downstream run between 29 June and 26 August (n=13 482) involved a much higher percentage of large fish. During this period an estimated 43.8% of downstream migrants exceeded 449 mm while 8.7% were larger than 499 mm. Gonadal examination and calculation of gonadosomatic indices (GSI) confirmed the presence of mature spawners among these early downstream migrants.

Between early July and late August, mean GSI values for mature downstream females in Freshwater Creek increased from 3.8 to 11.8. Data from this and other studies in the Mackenzie Delta-Beaufort Sea region indicate that the GSI increases rapidly throughout the summer and can exceed 20.0 by spawning time (Fig. 17, Table 14). In the Taz River of the Soviet Union, mean GSI values increased from 6.2 in late July to 9.7 in late August, while a mean of 20.4 was reached in late September in the Voikar River (Moskalenko 1971). Spawning occurs in late October and early November in both areas. Summer GSI values for non-spawning female broad whitefish at Tuktoyaktuk usually lie in the 0.4 to 0.6 range (Bond 1982).

Only two mature males were identified during the downstream migration although 31 males between 455 and 577 mm fork length were considered to be maturing (category 7). GSI values were not calculated for male whitefish and the subjective evaluations may have underestimated the maturity of some of these fish.

The youngest mature broad whitefish encountered in this study were age 10 (Table 10). The smallest mature female was 447 mm while the smallest mature male had a fork length of 471 mm.

Food habits: Young-of-the-year broad whitefish begin to enter streams of the Tuktoyaktuk Peninsula in late July, perhaps two months after emerging from spawning grounds in the Mackenzie River. Their food habits while in the estuary are unknown, although their small size would undoubtedly limit them to planktonic food.

Young whitefish captured in Freshwater Creek during September (n=30; 55-96 mm) had fed almost exclusively on zooplankton as copepods and cladocera accounted for 61.4% and 38.3%, respectively, of the total diet numerically (Table 15). Small chironomid larvae occurred in 40% of the stomachs but made up only 0.3% of all food items. The main planktonic species consumed, Epischura lacustris, Bosmina longirostris, and Daphnia longiremis, are freshwater forms that are often discharged into coastal areas during the summer (Grainger 1975). In the present instance, however, the condition of the food indicated clearly that it had been consumed recently, i.e., while the fish were in the stream. No empty stomachs were found among the 30 examined, and an average of 301 food organisms were counted per stomach (range 10-1031).

The trematode, Brachyphallus crenatus, was found in seven of the 30 young-of-the-year broad whitefish examined. The presence of this marine parasite provides evidence that young broad whitefish feed in the estuary prior to entering coastal streams (Dick and Belosevic 1981).

The food habits of larger broad whitefish were evaluated both during migration (at the fence sites) and in the lakes. At the Freshwater Creek fence site, 684 stomachs were examined during the two-year study, of which 30% were empty. Empty stomachs were more prevalent among upstream migrants (88%) than among downstream fish (69%). A detailed analysis of 66 stomachs containing food yielded an average degree of fulness of 28%. At the Mayogiak fence a different picture was observed. Here, only 10% of the stomachs were empty and, among the 80 stomachs that contained food, the average degree of fulness was 42% (Table 16). The difference between the results obtained at the two fence sites is believed to be related to the size of fish involved in the analysis, those at Mayogiak being considerably smaller than those at Freshwater.

Compared with fish captured at the fence sites, the frequency of empty stomachs was less and the quantity of food consumed tended to be greater among those taken in lakes. For broad whitefish from the Freshwater Lakes (n=79), 89% of the stomachs contained food and in these cases, 52% of the available food points were assigned. Results from the Mayogiak Lakes were similar as 91% of the stomachs contained food with an average degree of fulness of 63% (Table 16).

Broad whitefish captured in the lakes had consumed a variety of benthic invertebrates (Table A3.1; Bond and Erickson 1982) but the overall diet was dominated by Gastropoda, Pelecypoda, Amphipoda, and Diptera (mainly Chironomidae). These four groups accounted for 27%, 12%, 5%, and 9%, respectively, of the total food volume in fish from the Freshwater lakes while comprising 4%, 5%, 30%, and 14%, respectively, in lakes of the Mayogiak system (Table 16). The small molluscs, Valvata sincera helicoidea and Sphaerium sp., were the food items of greatest importance in most lakes. However, the amphipod, Gammarus lacustris, accounted for 61% of the total food volume of broad whitefish in Mayogiak Lake 3 while the notostracan, Lepidurus sp., made up 27% of the total food volume in Mayogiak Lake 2 despite occurring in only 11% of the stomachs (Bond and Erickson 1982). Lawrence et al. (1984) found that, in other freshwater lakes of Richards Island and the Tuktoyaktuk Peninsula, the diet of broad whitefish was dominated by Gastropoda, Pelecypoda, Chironomidae, Notostraca, and Amphipoda.

Overwintering: Many lakes of the Freshwater Creek system which serve as feeding areas during the summer are quite shallow (<2 m) and probably freeze solid in winter. However, late winter gillnetting and an analysis of the upstream and downstream migrations in Freshwater Creek (Fig. 13) clearly indicate that some lakes of this

watershed provide overwintering habitat for a significant number of broad whitefish.

The most important overwintering lake in the system is thought to be Lake 8 in which water deeper than 3 m accounts for 12.6% of the total surface area. Five species of fish, including four broad whitefish, were gillnetted from Lake 8 on 30-31 May 1982. Six broad whitefish were gillnetted from Lake 3 on 9 June 1982.

An estimate of the total number of broad whitefish overwintering in the Freshwater Creek drainage system can be derived from the fence counts and the calculated length-frequency distributions of the upstream and downstream migrants (Fig. 13). These data indicate that, for fish smaller than 225 mm, there was a net upstream movement of approximately 41 000 fish. Most of these fish were young-of-the-year or yearlings which entered the lakes during the summer but had not returned downstream by 12 October.

Among larger fish (>225 mm) the fence data indicate a net downstream movement of approximately 46 000. Most of these fish were juveniles; however, as mentioned earlier, the figure also included a number of spawners which had obviously spent the past winter in the lakes. The downstream run included 15 924 broad whitefish larger than 449 mm. Not all fish of this size would spawn in the current year, although it does not seem unreasonable to suggest that this number included at least several thousand spawners.

The discovery that considerable numbers of broad whitefish spend the winter prior to spawning in lakes of the Freshwater Creek drainage is a significant finding of this study. Several lakes on the Tuktoyaktuk Peninsula are known to provide overwintering for juvenile broad whitefish (Lawrence et al. 1984) but the majority of the spawning population is thought to overwinter in the Mackenzie River or Delta (Chang-Kue, personal communication).

The importance of the Mayogiak system as an overwintering area is not clear. Although no broad whitefish were captured through the ice in Lake 5, four pike were taken and there is no reason to believe that broad whitefish could not have overwintered there also. Fence results from 1981 (Bond and Erickson 1982) suggest some overwintering within the Mayogiak Lakes, especially of small broad whitefish (<225 mm). Clearly, however, the Freshwater Creek system is much the more important of the two in terms of providing overwintering habitat.

Lake whitefish

Timing of migrations: The upstream run of lake whitefish, consisting of 9 684 fish, began immediately after ice-out, peaked on 22 June, and was virtually complete (95%) by 15 July (Fig. 18). As with broad whitefish, an interruption of the upstream run between 27 June and 2 July coincided with a period of cooler weather and ice conditions. The pattern of the downstream migration (22 382 fish) also followed closely that observed for broad whitefish. Although downstream movement commenced in early July and continued throughout the summer, the most intense activity occurred in September and 85% of all downstream migrants passed the fence between 28 August and 6 October (Fig. 18).

Most lake whitefish migrated at night with little movement occurring during the daytime (Fig. 19). Sixty percent of upstream migrants passed the counting fence between 2200 and 0600 h while most downstream fish (64%) were taken between 1700 and 0100 h.

Length-frequency distribution: Length-frequency distributions based on measurements of 621 upstream and 3 317 downstream lake whitefish (Fig. 20 and 21) were applied to the total counts recorded during each indicated time period to produce length-frequency descriptions of the overall migrations (Fig. 22). Fork lengths for lake whitefish ranged from 94 to 465 mm in the upstream run and from 129 to 554 mm in the downstream migration. The majority of migrants were between 225 and 449 mm in both cases, accounting for 89% of the upstream and 98% of the downstream migration.

These results, and those obtained in 1981 (Bond and Erickson 1982), suggest limited use of the Mayogiak and Freshwater lake systems by small lake whitefish. Similarly, few small juveniles were captured during an earlier fence operation on the Tuktoyaktuk Peninsula (Chang-Kue, personal communication).

The modal size of lake whitefish captured at the fence site varied with time, the largest fish migrating first during both the upstream and downstream runs (Fig. 20 and 21).

Age and growth features: Scale ages were determined for 234 lake whitefish captured during the 1982 fence operation (Tables 17 and 18, Fig. 23). Efforts to age lake whitefish by means of otoliths and fin rays were generally unsuccessful; therefore a comparison of the three methods was not possible for this species.

Although scale ages for lake whitefish ranged from 1 to 18 years, the majority of fish in the runs, by inference from Table 18 and Fig. 22, appeared to be between 5 and 13 years. The data suggest that the downstream run was dominated by fish in age groups 7 to 10.

The observed growth rate for lake whitefish from Freshwater Creek (Fig. 23) is similar to that reported for this species by other studies in this area (de Graaf and Machniak 1977; Bond 1982).

Length-weight relationship and condition: The functional relationship between fork length and body weight for lake whitefish from Freshwater Creek (n=389, range 103-494 mm) is described by the equation:

$$\log_{10}W = 3.2842\ (\log_{10}L) - 5.6330;\ SD_b = 0.0261$$

No significant difference ($P>0.05$) was observed between the slopes ($F=0.4712$; 153 df) or elevations ($F=1.1486$; 154 df) of the length-weight regressions for males and females in the

upstream migration (Table 19). In the downstream run, however, the slopes for males and females differed significantly ($P<0.01$). Whether the high slope value for male whitefish in the downstream migration (3.5327) has biological significance or is simply an artifact related to sampling bias is not known. When the combined regressions for male and female lake whitefish (Table 19) were analyzed for covariance, a significant difference ($P<0.01$) was observed between the slopes ($F=3.4991$; 268 df) but not between the elevations ($P>0.05$; $F=0.5695$; 269 df). Length-frequency distributions for the lake whitefish samples used in the regression analysis are shown in Fig. 24.

Condition coefficients for individual lake whitefish were used to calculate mean K values for male and female fish during three different time periods, i.e., upstream June, downstream July-August, and downstream September (Table 20). Significant differences ($P<0.05$) were indicated by t-tests between the mean K values for males and females in both the upstream June and downstream July-August portions of the run. In both cases females had higher coefficients than did the males. These differences in condition are thought to reflect the more advanced state of sexual maturity among females. Of the 24 July-August females used in the calculations, 12 had been assigned to maturity category 3, having GSI values ranging from 1.9 to 8.1

Downstream fish taken in September were considerably smaller than those in the earlier samples (Table 20) and most were immature. No significant difference ($P>0.05$) was observed between the mean K values for male and female fish in this sample.

Condition factors tend to increase with increasing size of fish (Table 17). In the present study, however, the smaller September downstream fish had significantly higher K values than did the larger June upstream fish (Table 20). This was true for both males ($P<0.001$) and females ($P<0.01$). High K values in September are indicative of a successful summer feeding period.

Sexual maturity: Age and size at first maturity in lake whitefish vary greatly throughout the wide geographic range of the species (Healey 1975). In this area, lake whitefish generally mature for the first time between age 7 and age 11 (Stein et al. 1973; Alt and Kogl 1973; Percy 1975; de Graaf and Machniak 1977; Bond 1982). First maturity may be achieved at fork lengths of 350 mm or less, but most spawners in the Mackenzie River exceed 400 mm (Stein et al. 1973; K. Chang-Kue personal communication). Summer catches from coastal waters along the Tuktoyaktuk Peninsula consist primarily of non-spawning individuals (Galbraith and Hunter 1975; Jones and den Beste 1977; Byers and Kashino 1980; Bond 1982; Hopky and Ratynski 1983; Lawrence et al. 1984).

Migrations in Freshwater and Mayogiak creeks also consisted largely of non-spawning fish as suggested by the length-frequency distributions (Fig. 22; Bond and Erickson 1982). Gonadal examinations in 1981 identified only one potential spawner in each of these streams. A somewhat larger number of spawners or potential spawners was identified from Freshwater Creek in 1982.

During the 1982 fence operation on Freshwater Creek, 18% of the total upstream run and 16% of the downstream run exceeded 399 mm. These large individuals dominated the upstream migration during the last 10 days of June (31%) and accounted for 49% of the downstream run prior to 1 September.

Within this group of large fish, the gonads of 22 males were examined (6 up: 16 down) with only one individual (459 mm; 2 September) being identified definitely as a spawner. Spawning females were either more prevalent or more easily identified as examinations of 32 fish (14 up: 18 down) produced 13 spawners. Only one of these mature females (400 mm) was identified from the upstream run.

Between mid-July and late August, mean GSI values for mature female lake whitefish in Freshwater Creek (n=11, range 404-494 mm) increased from 4.0 to 8.0. Data from this and other studies in the Mackenzie Delta-Beaufort Sea region (Table 21, Fig. 25) indicate a rapid increase in the GSI in late summer with values as high as 20.9 being reached by mid-October. Summer GSI values for non-spawning female lake whitefish in Tuktoyaktuk Harbour varied from 0.3 to 1.2 (Bond 1982). Gonadosomatic indices were not calculated for male lake whitefish during the present study.

The youngest mature lake whitefish identified in Freshwater Creek in 1982 were age 11 (females) and age 15 (males). A seven-year-old female, 305 mm in fork length, was identified as mature in Mayogiak Creek in 1981 (Bond and Erickson 1982).

Food habits: The stomachs of 336 lake whitefish were examined at the Freshwater Creek fence site during the two-year study, of which 255 (76%) contained no food. Empty stomachs occurred in approximately equal proportions among upstream (77%) and downstream (74%) fish. A detailed analysis of 44 stomachs containing food (Table 22) indicated a higher degree of fulness in downstream fish (35%) than for upstream migrants (21%). Only 10 lake whitefish stomachs were examined from the Mayogiak Creek fence site, eight of which contained food (Bond and Erickson 1982; Table 22).

The food habits of lake whitefish in lakes of the Mayogiak system were not evaluated during this study. In lakes of the Freshwater Creek system, however, lake whitefish (n=19) had fewer empty stomachs (5%) and had consumed greater quantities of food (64% of food points assigned) than those taken at the fence site (Table 22).

Qualitative differences were observed between the stomach contents of upstream and downstream fish both at the Mayogiak and Freshwater fence sites. As shown in Table 22, Diptera comprised 32% and 20% of the food volume in upstream fish at Mayogiak and Freshwater, respectively. Among downstream migrants, Diptera were relatively less important (16% and 4%) while Gastropoda, Amphipoda, and Pelecypoda were

considerably more abundant. It is believed that much of the food found in the stomachs of upstream fish was acquired in the stream itself while most of the food in the stomachs of downstream fish had been consumed while in the lakes.

Lake whitefish captured in lakes of the Freshwater Creek system (n=18) had consumed a variety of benthic invertebrates, including immature Trichoptera, Plecoptera, and Ephemeroptera, Notostraca, Cladocera, Ostracoda, Nematoda, and Acarina (Bond and Erickson 1982). However, the overall diet in the lakes was dominated by Gastropoda which comprised 36% of the total food volume. Valvata sincera helicoidea was the most common gastropod, occurring in every stomach that contained food. Diptera larvae, Pelecypoda, and Amphipoda accounted for 5%, 3%, and 3%, respectively, of the overall diet in lake-caught fish (Table 22).

The extent to which lake whitefish feed during winter is unknown although food intake is probably reduced during this period of slow growth. Two lake whitefish captured under ice in Freshwater Lake 8 contained a small quantity of Gastropoda and digested material (Table A4.1).

Lake whitefish are known to feed to some extent along the coastal margin of the Beaufort Sea during the summer months (Kendel et al. 1975; Percy 1975; Jones and den Beste 1977; Bond 1982; Lawrence et al. 1984). A high incidence of empty stomachs is usually reported, however, for coastal fish and those whose stomachs contain food usually contain only small amounts.

Results of the present study suggest that lakes of the Freshwater drainage, and probably of the Mayogiak drainage as well, are important summer feeding areas for lake whitefish. Lakes of the Mackenzie Delta area are also known to provide major feeding areas for this species (Stein et al. 1973; Percy 1975; Lawrence et al. 1984).

Overwintering: Lake whitefish (n=2) were captured under ice only in Freshwater Lake 8. Both fish (a 352 mm female and a 373 mm male) were sexually immature and would not have spawned in 1982. The fact that downstream migrants outnumbered upstream migrants by 12 698 in the fence counts (Table 9) suggests a greater importance for this watershed in terms of overwintering habitat than is indicated by the gillnetting results. A small proportion of overwintering lake whitefish were potential spawners, although the majority were sexually immature.

Lawrence et al. (1984) suspect that several of the deeper lakes along the Tuktoyaktuk Peninsula and on Richards Island provide overwintering habitat for lake whitefish. The species has been taken under ice in the outer Mackenzie Delta (Percy 1975), in delta channels (Mann 1974), and in Tuktoyaktuk Harbour and Kugmallit Bay (Bond 1982).

Least cisco

At least two distinct forms of least cisco occur in the Mackenzie Delta-Beaufort Sea area. The anadromous form, described by many authors, spawns in the Mackenzie River (Stein et al. 1973), undertakes summer migrations into coastal areas of the Mackenzie estuary (Mann 1974; Percy 1975; Kendel et al. 1975; Galbraith and Hunter 1975; Bond 1982), and enters some small freshwater drainages of the Tuktoyaktuk Peninsula for feeding purposes (Bond and Erickson 1982; Chang-Kue, personal communication). The other form, a non-migratory, lake-spawning variety is apparently restricted to freshwater habitats and is absent from coastal locations (Lawrence et al. 1984). Lake dwelling least cisco from the Tuktoyaktuk Peninsula and Richards Island grow larger, are deeper bellied, are more darkly pigmented dorsally and in the ventral fins, and have a less extended lower jaw than does the anadromous form (Lawrence et al. 1984).

Both forms of least cisco were observed during the counting fence operations in Mayogiak and Freshwater creeks. An effort was made in 1982 to separate the two varieties but this was not always possible and both forms have been combined, therefore, for purposes of data analysis and discussion.

Timing of migrations: The 1982 upstream migration of least cisco in Freshwater Creek totalled 10 599 fish. Upstream movement began on 21 June but proceeded slowly until 2 July when the run appeared to begin in earnest. Forty-eight percent of the total upstream migration occurred between 2 and 24 July. The upstream migration (Fig. 26) was characterized by a series of peaks, separated by periods of relative inactivity. The peaks occurring prior to 25 August are considered to be representative of the actual run while those seen after 25 August were produced as a result of the need to seine small fish into the trap. As mentioned earlier, young least cisco (mostly young-of-the-year) had difficulty locating the entrance to the upstream trap and tended to hold just downstream of the fence. It is clear, however, that most upstream migrants had passed the fence site by early September.

Downstream activity was extremely slow until mid-August, by which time only 174 least cisco had been counted through the downstream trap. Activity began to increase in late August, however, and peaked on 28 September. A total of 5229 cisco were counted through the downstream trap, the majority (76%) passing the fence between 15 September and 9 October (Fig. 26).

As was the case for the other anadromous species, a strong diel periodicity was noted for least cisco in both the upstream and downstream runs (Fig. 27). Most upstream movement observed prior to 20 August (75%) occurred between 1700 h and 0400 h. Downstream movements were heaviest (59%) between 1900 h and 0400 h, peaking just before midnight.

Length-frequency distribution: Fork length measurements for 1 520 upstream and 966 downstream least cisco (Fig. 28 and 29) were used to produce estimated length-frequency descriptions of the overall migrations (Fig. 30).

The upstream migration had a distinctly bimodal length-frequency distribution. Although

upstream fish ranged in length from 48 to 383 mm, the majority were either in the 50-149 mm size range (53%) or between 250 and 349 mm (30%). Fork lengths of downstream cisco varied from 69 to 389 mm with 83% falling in the 200-349 mm size range. The length-frequency distribution for downstream least cisco coincided almost exactly with that of the larger segment of the upstream run.

The length-frequency distribution varied over time as large individuals tended to migrate first. This trend was especially evident during the upstream run (Fig. 28) and in the latter stages of the downstream migration (Fig. 29). During the first week of the upstream run (22-30 June), 75% of the fish were 300-349 mm in length. By 8-14 July, 63% were between 200 and 249 mm, and during the period 22 July to 9 August, 52% were in the 100-124 mm range. Among upstream migrants measured between 26 August and 1 October, 60% had fork lengths of 50 to 99 mm.

Age and growth features: Scale ages were determined for 385 least cisco from the 1982 Freshwater Creek counting fence operation. Comparisons between scale age and otolith age were made for 59 of these fish. Similar comparisons were performed in 1981 for 70 least cisco from Freshwater Creek and 92 from Mayogiak Creek (Bond and Erickson 1982).

Overall, agreement (±1 year) between scale age and otolith age was 79%. The best agreement occurred within the youngest age groups although substantial discrepancies were observed as early as age 1 (Fig. 31). Among least cisco age 5 and older, agreement (±1 year) between scale age and otolith age was only 49%. In almost all cases where results obtained by the two methods did not agree, the otolith age was greater than the scale age.

Scale ages were compared with fin-ray ages in 63 cases. Results obtained by these two methods were very comparable (Fig. 31) with agreement (±1 year) being 94%. In most cases in which scale age and fin-ray age disagreed, the fin-ray age was greater than the scale age.

The results of this preliminary comparison suggest that scales may underestimate age in least cisco and that this tendency may increase substantially after age 4.

Age and growth features for least cisco captured during the 1982 counting fence operation in Freshwater Creek are summarized in Table 23 and Fig. 32. Table 24 presents length-frequency distributions for fish in each age group.

Scale ages ranged from 0+ to 11 years but obvious differences occurred between the age structures of the upstream and downstream runs. Considering fork length as an indication of age, Fig. 30 suggests that the early part of the upstream migration, as well as the downstream run, consisted primarily of least cisco ageed 4 to 9 years and, most frequently, 6 to 8 years.

Whereas the downstream run included few individuals younger than age 3, such young fish were common in the upstream run after mid-July. The major mode occurring between 50 and 149 mm (Fig. 30) consists mainly of young-of-the-year (0+), yearlings, and two-year-olds. Young-of-the-year least cisco first appeared in the upstream migration on 29 July and were the most abundant age group captured after 25 August. Young-of-the-year least cisco in the 50-74 mm range were also encountered in early August upstream migrations in Mayogiak and Freshwater creeks during 1981 (Bond and Erickson 1982).

The observed growth rate for least cisco from Freshwater Creek (Table 23, Fig. 32) is similar to that reported for this species by other studies in this area (Mann 1974; Bond 1982; Lawrence et al. 1984). It is to be remembered that our data represent a composite, including both anadromous and non-migratory lake-type least cisco. Lawrence et al. (1984) suggest that the latter grow faster and achieve larger sizes than the anadromous type.

Length-weight relationship and condition: The overall mathematical relationship between fork length and body weight for Freshwater Creek least cisco (n=429, range 65-383 mm) is described by the equation:

$$\log_{10}W = 3.1700\ (\log_{10}L) - 5.4318;\ SD_b = 0.0203$$

Comparisons of males and females by analysis of covariance indicated no significant difference ($P>0.05$) between the slopes within the upstream run ($F=0.0912$; 158 df), within the downstream run ($F=0.2788$, 92 df), or in the combined samples ($F=0.0849$, 254 df). A similar comparison of elevations showed no significant difference ($P>0.05$) between male and female least cisco in the upstream ($F=1.3273$; 159 df) or downstream ($F=1.6336$; 93 df) migrations, although a significant difference ($P<0.01$) was observed between the sexes in the combined sample ($F=2.0896$; 255 df). Length-weight regressions for least cisco in Freshwater Creek are summarized in Table 25. Length-frequency distributions for fish used in the calculations are shown in Fig. 33.

Condition factors for individual least cisco were used to calculate mean K values for male and female fish in three different time periods; i.e., upstream June-July, downstream July-August, and downstream September. Because t-tests indicated no significant differences ($P>0.05$) between the mean K values for males and females within time periods these data were combined (Table 26). The mean condition coefficient for upstream migrants was quite low (0.8738) and differed significantly ($P<0.001$) from that determined for downstream fish. No difference was observed, however ($P>0.05$), between fish in the two downstream phases. The improved condition demonstrated by downstream fish reflects, in part, a more advanced state of sexual maturity in some individuals and suggests a successful summer feeding period.

Sexual maturity: Sexually mature least cisco were identified at both the upstream (n=20) and downstream (n=41) traps during 1982. Upstream captures were scattered throughout the study period, occurring between 26 June and 1 October. Most mature downstream migrants were cap-

tured in late August (63%) and early September (29%).

The youngest mature least cisco identified during the study was an age 4 female (230 mm) taken in Freshwater Creek in 1981. (Reported previously as age 3 (Bond and Erickson 1982)). It is clear that few cisco mature before age 4 or 5 (Table 23; Bond and Erickson 1982) or at fork lengths below 250 mm. Most studies in the Beaufort Sea have placed the age of first maturity at between 4 and 9 years (Stein et al. 1973; Mann 1974; Griffiths et al. 1975; Percy 1975; Bond 1982). Spawning runs in the Mackenzie River were dominated by age groups 6 to 8, with most individuals falling in the 271-280 mm size range (Stein et al. 1973).

Our data suggest that male least cisco mature at a younger age and at a smaller size than females. Mature males (n=26) had a mean age of 6.5 years and a mean fork length of 301 mm compared with 7.9 years and 321 mm for females (n=35). The tendency for male least cisco on the Beaufort Sea coast to mature at a younger age than females has also been noted by Mann (1974), Craig and Haldorson (1981), and Bond (1982). Modal fork lengths among Mackenzie River spawners were 320 mm for females and 290 mm for males (Hatfield et al. 1972).

The upstream and downstream migrations in 1982 included an estimated 3 217 and 3 580 least cisco, respectively, with fork lengths greater than 250 mm (Fig. 30). Our data suggest that as many as half these fish were sexually mature. For example, among downstream fish of this size captured prior to 15 September, 44% of the males (n=34) and 56% of the females (n=48) examined would have spawned during the current year. For fish taken in the upstream run prior to 15 July, the corresponding figures were only 18% for males (n=22) and 6% for females (n=36). The difference between the two sets of numbers is thought to be indicative of the difficulty encountered in trying to identify potential spawners early in the year by subjective gonadal examination.

GSI values for mature least cisco in Freshwater Creek were in the 1.5 to 2.1 range in July but increased rapidly during August, and reached a mean of 9.8 by early September. Data from the Mackenzie River indicate that the GSI can reach 20.3 by early October (Table 27, Fig. 34). Spawning occurs in the Mackenzie River in late September and early October (Stein et al. 1973).

Food habits: The stomachs of 293 least cisco were examined during 1982. Among these fish, all of which were captured at the fence site, 55% contained no food. The incidence of empty stomachs was considerably greater for upstream fish (63%) than for downstream migrants (40%). Furthermore, when one compares only those stomachs that contained food, upstream fish usually contained less than those taken at the downstream trap. This fact is somewhat masked by the relatively large contribution of a small number of ninespine stickleback to the total food volume for upstream migrants (Table 28).

Laboratory analysis of 74 stomachs containing food revealed a diet based heavily on planktonic Crustacea (Table 28). Although the food contained small numbers of aquatic insects, amphipods, ostracods, arachnids, nematodes, and fish, Cladocera dominated the stomach contents both numerically and volumetrically. This dominance was more evident among downstream fish, in which Cladocera comprised 97.4% of the food in terms of numbers while accounting for 64.2% of the volume. Sixteen of 37 downstream fish contained more than 10 000 Cladocera while one fish had consumed an estimated 66 600. The stomachs of downstream fish contained an average of 12 366 Cladocera while upstream migrants contained only 1 800 per stomach.

Considering their dominance in the stomach contents, Cladocera would appear to have been selected by least cisco over other available food items. None of the cisco that we examined was captured in the lakes; however, since the fence was located only a short distance downstream of the lakes it seems likely that some of the food in the stomachs would have been consumed in the lakes prior to entering the stream. Yet, the food contained no molluscs, no oligochaetes, and few diptera, groups that dominate the benthic fauna in lakes of the Freshwater system (Table 5).

The diet of least cisco in Freshwater Creek resembles closely that described by Lawrence et al. (1984) for this species in lakes north and east of our study area on the Tuktoyaktuk Peninsula. Conversely, in lakes south and west of Tuktoyaktuk, these authors found the predominant food of least cisco to be amphipods, molluscs, conchostracans, and fish while on Richards Island, molluscs, insects, and fish were the major food items.

The lakes and streams of Richards Island and the Tuktoyaktuk Peninsula are clearly important feeding areas for least cisco. Although the diet may vary between watersheds, ciscoes captured in these freshwater systems generally have fewer empty stomachs, fuller stomachs, and a more diversified diet than those taken in coastal areas (Kendel et al. 1975; Percy 1975; Jones and den Beste 1977; Bond 1982; Lawrence et al. 1984).

Overwintering: No least cisco were captured under ice in Mayogiak Lake 5 or in Freshwater Lake 3. A single fish (273 mm) taken in Freshwater Lake 8 on 30 May 1982 proved to be a seven-year-old mature male. Whether this specimen was a lake type or anadromous least cisco was not determined. Least cisco, supposedly anadromous, have been captured under ice in coastal areas (Percy 1975; Galbraith and Hunter 1975; Steigenberger et al. 1975; Bond 1982) and in lakes of the Mackenzie Delta (Jessop and Lilley 1975). Lake type least cisco are known to overwinter in the Canyanek system just west of Tuktoyaktuk (Lawrence et al. 1984).

Although only one fish was taken from the Freshwater lakes under ice, the fence counts and the calculated length-frequency distributions in the upstream and downstream runs (Fig. 30) provide strong evidence that considerable numbers of small juveniles overwinter within the watershed. As Fig. 30 indicates, the upstream migration included 5 626 least cisco with fork lengths less than 150 mm (young-of-the-year and

yearlings). Only 329 fish in this size range had returned downstream by 12 October.

The extent to which the Freshwater Creek drainage is used as overwintering habitat by larger least cisco is unclear. The close overlapping of the length-frequency distributions for larger fish in the upstream and downstream runs (Fig. 30) is suggestive of a group of fish migrating into and then back out of the watershed. This attractively simple interpretation is clouded, however, by the knowledge that the runs included two different forms of the species which may have distinctly different migratory patterns.

CONCLUSION

This study documents the occurrence of substantial coregonid migrations in Mayogiak and Freshwater creeks, and establishes the lakes of these two watersheds as important feeding, rearing, and overwintering habitat for broad whitefish, lake whitefish, and least cisco. In terms of describing the diel and seasonal pattern of migrations, the size frequency, age composition, and sexual maturity of migrants, it provides a level of detail not previously available for coregonids in this region. Such information, we believe, improves our understanding of the life histories of these species and places in clearer perspective the results of previous studies in the Mackenzie Delta-Beaufort Sea area.

Coregonid life histories in the lower Mackenzie River include complex migratory movements involving all members of the populations. Movements of spawners within the Mackenzie River and Delta have been well documented (Hatfield et al. 1972; Stein et al. 1973; Jessop and Lilley 1975; Percy 1975; de Graaf and Machniak 1977). Throughout the summer and early autumn, members of the various spawning stocks migrate upstream through the Delta to spawning sites in the Mackenzie River and certain major tributaries. After spawning between late September and early November, the spents return to overwintering sites in the Delta or inner estuary.

Less well understood have been the migratory patterns of the juvenile members, especially the very small juvenile members, of these populations. Studies in the mid-1970's indicated that large numbers of coregonids entered the southern Beaufort Sea each summer and dispersed along the coastal margin (Mann 1974; Craig and Mann 1974; Percy 1975; Kendel et al. 1975; Galbraith and Hunter 1975; Griffiths et al. 1975). Most of the fish encountered appeared to be juveniles on feeding migrations, suggesting an important role for coastal habitats as feeding and rearing areas. Later studies (Griffiths et al. 1977; Jones and den Beste 1977; Craig and Haldorson 1980; Bond 1982; Lawrence et al. 1984) confirmed the significance of the inshore in this regard.

Recent work by the Department of Fisheries and Oceans, however, shed a new light on the situation by demonstrating the occurrence of large migrations of broad whitefish, lake whitefish, and least cisco into coastal streams of the Tuktoyaktuk Peninsula, and by linking these fish, through tagging studies, to the Mackenzie River stocks (Chang-Kue, personal communication). Lawrence et al. (1984) indicated that such migrations occurred in numerous streams draining into the Beaufort Sea from Richards Island and the Tuktoyaktuk Peninsula.

The capacity to utilize coastal habitats demands some level of salinity tolerance on the part of the fish. Although little is known concerning the specific tolerance limits of the anadromous coregonids of the Mackenzie Delta-Beaufort Sea region, it is evident from distribution patterns that salinity tolerance varies between species. Arctic cisco, for example, appear to be particularly tolerant of high salinities and enjoy a wide coastal distribution. It has been suggested recently, in fact, that the Arctic cisco commercial fishery at the Colville River, Alaska (400 km west of the Mackenzie), is based on Mackenzie River stock (Gallaway et al. 1983). On the other hand, the occurrence of broad whitefish, lake whitefish, and least cisco in coastal waters of the Canadian Beaufort Sea is largely restricted to nearshore areas of the Mackenzie Delta and Tuktoyaktuk Peninsula where the freshening influence of the Mackenzie River is greatest. Especially significant, we believe, in determining the coastal distribution of broad whitefish, lake whitefish, and least cisco, and providing access to the coastal streams, is the freshwater environment created under winter ice cover by Mackenzie River discharge.

During summer, anadromous coregonids are common along the coast of the Tuktoyaktuk Peninsula. Many of these fish are assumed to be in migration although as Bond (1982) points out, interpretation of catch-per-unit-effort data is made difficult by the possibility that migrations may be occurring in different directions simultaneously. Although little winter work has been done in this area, most coregonids are thought to abandon coastal habitats in late summer. Bond (1982) detected pronounced increases in coregonid abundance at Tuktoyaktuk in September, suggesting a concerted movement toward the Mackenzie at that time.

The annual dispersal of juvenile broad whitefish, lake whitefish, and least cisco away from Delta overwintering sites into coastal habitats is thought to start under ice cover. It may occur gradually throughout the winter, following the under-ice expansion of the freshwater zone created by Mackenzie flow. In any event it is evident that the movement is led by the largest fish, which arrive in the vicinity of the creek mouths before the creeks begin to flow in the spring. In the present study, and in previous studies (Chang-Kue, personal communication), upstream migrations into coastal streams began almost immediately the streams became ice-free.

The fact that the streams begin to flow before the sea ice breaks up may be a critical factor in the course of coastal migrations. It permits many fish to move from Mackenzie Delta wintering sites to lakes on the Tuktoyaktuk Peninsula without encountering salt water. The longer the land fast ice remains in place, of

course, the longer the freshwater zone remains intact. Thus, inshore coastal areas can remain relatively fresh for some time after the streams open. For example, in 1979, Kukjuktuk Creek broke on 12 June, but salinities, measured 3 km offshore from the entrance to Kukjuktuk Bay (Fig. 1), remained below 5 ‰ until mid-July. After mid-July, salinity increased sharply, reaching 34 ‰ by mid-August (B. Fallis, personal communication).

The present study suggests that, while the lake systems of the Tuktoyaktuk Peninsula are of significance to broad whitefish, lake whitefish, and least cisco, they are particularly important in the life history pattern of the broad whitefish. In Mayogiak and Freshwater creeks, as in other streams on Richards Island and the Tuktoyaktuk Peninsula (Chang-Kue, personal communication; Lawrence et al. 1984), broad whitefish outnumbered the other two species by a wide margin. On the basis of our observations in Mayogiak and Freshwater creeks, and considering information provided by other studies, the life history of broad whitefish in the Mackenzie Delta-Beaufort Sea area appears to involve a characteristic pattern of migration.

Although many members of the spawning stock overwinter within the Delta itself, others, as the present study has indicated, that passed the winter prior to spawning in lakes of the Tuktoyaktuk Peninsula, begin to leave their overwintering sites in early summer and move toward the Mackenzie Delta. They began to leave the Freshwater Creek system in late June and early July, mature individuals being captured moving downstream throughout July and August. By September, spawners have abandoned coastal habitats and have concentrated within large back-eddies of the lower Mackenzie River and Delta. Spawning occurs in the Mackenzie and certain major tributaries in late October and early November, followed by a post-spawning, downstream movement of spents to the Delta or inner estuary.

It is unclear how frequently broad whitefish spawn once first maturity has been reached. Moskalenko (1971) suggested a two-year periodicity in Soviet Union stocks. On the other hand, a high incidence of consecutive year spawning was observed in broad whitefish of the Chatanika River, Alaska (Kepler 1973). It is clear that in the Mackenzie River populations there are some individuals that do not spawn every year. Bond (1982) reported capturing two mature non-spawners (fish that have spawned previously but will not spawn in the current year) in Tuktoyaktuk Harbour, while one such fish was identified at Freshwater Creek during the present study. The incidence of mature non-spawners in the Mackenzie Delta-Beaufort Sea area appears to be very low, however, suggesting that consecutive year spawning may be common here.

Overwintering sites for consecutive year spawners are restricted to the lower Mackenzie River and inner estuary as coastal streams have little flow by the time of the post-spawning migration in November. Most of the spawners observed leaving Freshwater Creek in 1982 were first time spawners.

Whitefish eggs remain in the gravel over the winter and hatch in the spring. Upon emerging, broad whitefish fry are presumed to be carried downstream by the spring flood, reaching the Delta by early June. Some find nursery areas in Delta lakes, but many are swept into the estuary which is still fresh and ice-covered at this time. Within this freshened zone, the young-of-the-year migrate along the coast, reaching Tuktoyaktuk by early July (Bond 1982). In late July and August, the young whitefish migrate in large numbers up coastal streams into tundra lakes on the Tuktoyaktuk Peninsula. Both Mayogiak and Freshwater creeks are important in this regard but other streams on Richards Island and on the Tuktoyaktuk Peninsula are also utilized (Chang-Kue, personal communication; Lawrence et al. 1984). While in the streams the young whitefish feed intensively on planktonic crustacea which drift downstream from the lakes.

As evidenced by the large number of yearlings in the upstream migrations, not all broad whitefish are successful in reaching the lakes during their first summer. It may be that some individuals arrive late in the estuary, find conditions too saline to permit coastal migration, and are forced to overwinter within the Delta or inner estuary.

Having reached nursery areas within the lake systems, the young broad whitefish appear to remain for up to four years before re-entering coastal waters. During this time their diet changes from planktonic to epibenthic food and their average fork length increases to more than 250 mm. They then join a group of large juveniles (mainly 225-474 mm), many of which may undertake annual migrations between overwintering sites in the Mackenzie Delta and summer feeding areas in lakes of the Tuktoyaktuk Peninsula until the age of maturity is attained. Fish of this size range account for most of the upstream migrations that commence at ice-out in coastal streams of this region, as well as the majority of the heavy downstream runs noted in late August and September. Most broad whitefish gillnetted at coastal locations in the southern Beaufort Sea also fall within this size range.

The lake whitefish appears to be more a fish of the lower Mackenzie River and inner estuary where it is reported to be more abundant than the broad whitefish (Percy 1975). The extent of its coastal migrations, and its utilization of the lake systems of the Tuktoyaktuk Peninsula appear much more limited than is the case for broad whitefish. While the lakes provide feeding and overwintering areas for some large juveniles and spawners, the available evidence suggests they are not utilized to any significant degree by small juveniles. In the present study, for example, the upstream migrations into the lakes included few lake whitefish younger than age 4 or less than 225 mm in fork length. Similar observations were reported from other coastal streams in this area (Chang-Kue, personal communication; Lawrence et al. 1984).

The major nursery areas for lake whitefish appear to be located within the Mackenzie Delta and inner estuary. Large numbers of young-of-the-year are captured in back eddies of East Channel throughout the summer (E. Jessop, per-

sonal communication) while few have been reported from Tuktoyaktuk (Bond 1982; Hopky and Ratynski 1983) or from other coastal locations (Lawrence et al. 1984). On the other hand, numerous lake whitefish in the 125 to 224 mm size range (probably age 1-3) were captured in Tuktoyaktuk Harbour during summer, 1981 (Hopky and Ratynski 1983), suggesting that coastal habitats near the month of the Mackenzie may be important foraging sites for young lake whitefish other than young-of-the-year.

Lake whitefish spawn in October, several weeks prior to broad whitefish (Stein et al. 1973; Percy 1975). Overwintering fish have been taken in the outer Mackenzie Delta (Percy 1975), in Delta channels (Mann 1975), in Tuktoyaktuk Harbour and Kugmallit Bay (Bond 1982), and in several lakes of Richards Island and the Tuktoyaktuk Peninsula in addition to the present study (Lawrence et al. 1984).

The occurrence of two distinctly different varieties of least cisco in our area greatly complicates the life history picture for this species. Both varieties were identified in Mayogiak and Freshwater creeks during the present study. In Freshwater Creek in 1982, the upstream migration of large fish, occurring in late June and early July, and the downstream migration in late August and September included both types of cisco. Furthermore, for both varieties, mature individuals, i.e. fish that would spawn in the current year, were included in both the upstream and downstream runs.

Anadromous least cisco are thought to return to the Mackenzie River when mature, and to spawn in late September and early October in the Peel and Husky channels of the Delta, the Peel River, and the Arctic Red River (Stein et al. 1973). The movement of mature anadromous cisco out of Freshwater Creek in late August and early September is consistent with such a pattern.

The movements of lake-type least cisco in Freshwater Creek, however, appear to conflict with previous reports regarding the life history pattern of this variety. Lawrence et al. (1984) believe that the lake dwelling cisco spawns and overwinters within lakes and that, while it may migrate between lakes within a system, it does not venture into coastal waters. Mann (1974) described such a freshwater migratory population in Peter Lake, located at the headwaters of Holmes Creek which drains into the East Channel of the Mackenzie Delta.

It seems clear from our observations in Freshwater Creek that some lake-type least cisco utilize this watershed only on a seasonal basis, migrating into the lakes shortly after ice-out, and leaving prior to freeze-up. Where this group of fish spawns and overwinters remains a mystery. It should be noted though, that two ripe least cisco (a male and a female) were captured in Freshwater Creek on 30 September 1982. Both were of the lake type and, although taken in the upstream trap, both were captured during a seining operation and may have been downstream migrants.

Although it cannot be said with certainty, the small least cisco encountered in our study (<150 mm) are thought to be of the anadromous variety. If so, the early life history of anadromous least cisco appears to have some elements in common with that of the broad whitefish. Young least cisco are known to disperse during early summer to coastal habitats within the Mackenzie Estuary (Kendel et al. 1975; Percy 1975; Lawrence et al. 1984). Bond (1982) reported that young-of-the-year least cisco began to appear in Tuktoyaktuk Harbour in mid-July. Coastal habitats are, undoubtedly, important feeding areas for these young fish. Some of the young may remain in coastal waters but others migrate upstream into tundra lakes where they may reside for several years before returning to the coast. Both Mayogiak and Freshwater creeks provide nursery areas for such small ciscoes, as do other lake systems on the Tuktoyaktuk Peninsula (Chang-Kue, personal communication). Many lakes of the Mackenzie Delta also provide nursery areas for least cisco.

As Craig (1984) points out, the migrations of arctic anadromous fishes are not as impressive as the oceanic excursions of southern salmonid stocks. Generally, they are confined to a very narrow band along the shoreline, and, in the case of the whitefish and least cisco, to the immediate vicinity of the river of origin. Yet, the life histories of these northern species are highly complex, involving migratory strategies that link a diversity of widely separated habitat types.

Some of the advantages of such complex life histories, including the feature of anadromy, have been discussed by Bain (1974), Craig and McCart (1976), and McCart (1980), largely in relation to Arctic charr. To these authors, the ability to enter the sea and utilize the greater food resources of the marine environment results in faster growth and larger size, with benefits being realized in terms of increased reproductive capacity among females. The extent to which this is true in broad whitefish, lake whitefish, and least cisco is unknown, although these species certainly do benefit to some extent from the food resources available in nearshore areas of the Mackenzie estuary. This may be especially so in the case of the very young fish. Although the food habits of these small fish within the estuary have not been examined to date, feeding by young-of-the-year broad whitefish and least cisco must occur within the estuary prior to late July when they begin to enter coastal streams.

The use of tundra lakes by broad whitefish (especially), lake whitefish, and least cisco may result in many advantages to these populations. In the first place, since many lakes are utilized in numerous systems along the Tuktoyaktuk Peninsula and Richards Island, the populations tend to be spread out over a wide area, thus reducing intra-specific competition and ensuring that the populations are protected against isolated catastrophic events.

The lakes themselves, with warm summer water temperatures (up to 18.5°C) and abundant populations of benthos and plankton, may provide nearly ideal growing conditions in a region where the growing season is restricted. Such conditions may permit a more rapid rate of growth than could be achieved elsewhere. In the

case of broad whitefish and least cisco, which enter the lakes as young juveniles, a rapid early growth rate may allow fish to mature sexually and join the spawning stock at a younger age.

Reduced predation may also be a benefit gained by young coregonids utilizing the tundra lakes. Northern pike and burbot are not nearly as abundant in these lakes as they are in the lakes and channels of the Mackenzie Delta.

Several lakes on the Tuktoyaktuk Peninsula, including some in the Freshwater and Mayogiak systems, are deep enough to provide overwintering areas for fish. Such areas, as the present study suggests, are used extensively by anadromous coregonids, permitting the population to remain dispersed during the critical winter period.

Peterson (1982) stressed the need to adopt a system-wide approach to habitat management in situations where fish life histories were characterized by many different habitat types separated by considerable distances. In other words, where production depends ultimately upon the complementary nature of many habitat types it is insufficient to protect e.g., spawning locations, while permitting distant nursery areas to deteriorate. This point would appear to be well taken in the case of the anadromous coregonids of the Mackenzie Delta-Beaufort Sea area. As industrial development proceeds in this region, it will be necessary to ensure that critical fish habitats, spawning, feeding, and overwintering sites, are protected from degradation, and that migration corridors between such sites are maintained.

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Table 1. Summary of morphometric data for selected lakes in the Mayogiak and Freshwater Creek watersheds.[1]

Lake	Location	Parameters							
		A (ha)	L (km)	W (km)	Z (m)	$\bar{Z}$ (m)	V (x 1000 m^3)	SL (km)	D
Mayogiak System									
Lake 1	69°24'N; 132°55'W	23.6	1.1	0.3	0.5	0.2	55	2.6	1.5
Lake 2	69°24'N; 132°52'W	73.4	1.2	1.0	1.0 (2.0)	0.7	544	3.8	1.3
Lake 3	69°23'N; 132°51'W	331.4	3.5	1.7	1.0 (3.0)	0.8	2767	9.8	1.5
Lake 5	69°20'N; 132°54'W	440.0	5.3	2.2	4.0	1.1	4778	17.9	2.4
Freshwater System									
Lake 1	69°26'N; 132°49'W	560.2	4.0	2.3	1.5 (2.25)	0.8	4356	14.3	1.7
Lake 2	69°24'N; 132°46'W	817.3	6.4	2.4	1.0 (2.0)	0.6	5250	16.7	1.6
Lake 3	69°27'N; 132°37'W	180.7	2.0	1.9	5.0	1.2	2238	7.6	1.6
Lake 8	69°19'N; 132°50'W	1235.5	8.8	3.4	8.0	1.5	18807	34.0	2.6

[1] Maximum Depths determined by hand sounding are shown in parentheses.
Abbreviations:

A: Surface area of lake
L: Maximum length
W: Maximum width
Z: Maximum depth
$\bar{Z}$: Mean depth (V/A)
V: Volume
SL: Shoreline length
D: Shoreline development factor

Table 2(a). Summary of physical and chemical data from lakes of the Mayogiak Creek watershed.

Parameter	Mayogiak Lakes				
	1	2	3	5	
	(29/8/81)	(31/7/81)	(5/8/81)	(14/5/82)	(25/8/82)
Water Temperature (°C)	18.0	15.0-16.0	10.5-11.0	≈0	8.0
Secchi Disc Transparency (m)	0.8	1.9	0.7		1.7
pH	7.45-8.15	8.15-8.80	7.90-7.91	6.90	
Dissolved Oxygen ($mg \cdot L^{-1}$)	8.9	10.4	11.0-12.0	5.0[1,2]	
Specific Conductance ($\mu S \cdot cm^{-1}$)	763-781	144-145	145-147		
Ice Thickness (m)				1.6	
Water Under Ice (m)				1.0	
Total Dissolved Nitrogen ($\mu g \cdot L^{-1}$)				690	
Total Dissolved Phosphorus ($\mu g \cdot L^{-1}$)				11	
Chlorophyll a ($\mu g \cdot L^{-1}$)				1.3	
Suspended Reactive Silica ($mg \cdot L^{-1}$)				0.752	
Total Suspended Solids ($mg \cdot L^{-1}$)				7	
Suspended Phosphorus ($\mu g \cdot L^{-1}$)				19	
Suspended Nitrogen ($\mu g \cdot L^{-1}$)				251	
Suspended Carbon ($\mu g \cdot L^{-1}$)				1540	
Dissolved Organic Carbon ($\mu Mole \cdot L^{-1}$)				1420	620-670

[1] Determined in field using Hach Kit
[2] 31 May 1982

Table 2(b). Summary of physical and chemical data from lakes of the Freshwater Creek watershed.

Parameter	Freshwater Lakes							
	1		2		3		8	
	(25/7/81)	(7/8/82)	(25/7/81)	(7/8/82)	(27/7/81)	(14/5/82)	(12/5/82)	(11-12/7/82)
Water Temperature (°C)	17.5-18.5	9.9-10.3	17.5-18.5	9.4-10.0	17.0-18.0	≈0	≈0	11.0-11.5
Secchi Disc Transparency (m)	2.25	1.30	1.30	1.45	3.8			2.5
pH	7.35-8.25		7.95-8.05		8.46-8.60	6.96	6.93	
Dissolved Oxygen ($mg \cdot L^{-1}$)	10.6-10.8		10.0-10.4		10.1-11.1	2.0[1,3]	7.0[1,4]	
Specific Conductance ($\mu S \cdot cm^{-1}$)	162-163		156		163-209			
Ice Thickness (m)						1.8	1.7	
Water Under Ice (m)						0.5	1.2	
Total Dissolved Nitrogen ($\mu g \cdot L^{-1}$)						620	530	
Total Dissolved Phosphorus ($\mu g \cdot L^{-1}$)						11	8	
Chlorophyll a ($\mu g.L^{-1}$)						7.2	2.1	
Suspended Reactive Silica ($mg \cdot L^{-1}$)						0.583	0.551	
Total Suspended Solids ($mg \cdot L^{-1}$)						45	1	2
Suspended Phosphorus ($\mu g \cdot L^{-1}$)						75	6	
Suspended Nitrogen ($\mu g \cdot L^{-1}$)						606	111	59-62
Suspended Carbon ($\mu g \cdot L^{-1}$)						3840	590	330-412
Dissolved Organic Carbon ($\mu Mole \cdot L^{-1}$)						1210	1090	610-1040

[1] Determined in field using Hach Kit
[3] 8 June 1982
[4] 30 May 1982

Table 3. Zooplankton identified from lakes of the Freshwater and Mayogiak watersheds during 1981 and 1982.

Species	Freshwater System				Mayogiak System		
	Lake 1	Lake 2	Lake 3	Lake 8	Lake 1	Lake 2	Lake 3
Copepoda							
Calanoida							
Eurytemora sp.	+	+	+				+
Epischura lacustris	+	+					
Diaptomus pribilofensis	+	+				+	+
Heterocope septentrionalis						+	
Diaptomid copepodids	+	+	+				
Diaptomid nauplii					+		
Calanoid nauplii				+			
Harpacticoida							
Harpacticoid copepodids				+			
Cyclopoida							
Cyclops bicuspidatus	+	+	+	+	+		+
Cyclops vernalis					+		+
Cyclops sp.	+	+	+				
Cyclopoid copepodids	+	+	+	+	+		+
Cyclopoid nauplii	+	+	+	+	+	+	+
Cladocera							
Daphnia longiremis	+	+			+		
Daphnia galatea	+	+					+
Daphnia sp.	+	+					
Ceriodaphnia quadrangula					+	+	
Bosmina longirostris	+	+	+	+	+	+	+
Eubosmina longispina	+	+					
Eubosmina sp.	+	+					
Chydorus sphaericus					+	+	+
Chydorus sp.	+	+	+				
Holopedium gibberum	+	+					

Table 4. Composition and density (No./m²) of benthic invertebrates in lakes of the Mayogiak Creek watershed, 1981-1982.

Taxa	Lake 1 (1981) Density (No./m²)	%	Lake 2 (1981) Density (No./m²)	%	Lake 3 (1981) Density (No./m²)	%	Lake 5 (1982) Density (No./m²)	%
Mollusca			1047	70	108	42	442	28
Diptera	43	100	287	19	65	25	861	55
Oligochaeta			115	8	43	17	237	15
Amphipoda			29	2	43	17	32	2
Others			28	2				
Total	43		1506		260		1572	
Number dredge hauls	1		3		2		4	
Number animals counted	1		105		12		146	
Total wet weight (g)	<0.01		0.30		0.03		0.21	

Table 5. Composition and density (No./m²) of benthic invertebrates in lakes of the Freshwater Creek watershed, 1981-1982.

Taxa	Lake 1 1981 No./m²	%	Lake 1 1982 No./m²	%	Lake 2 1981 No./m²	%	Lake 2 1982 No./m²	%	Lake 3 1981 No./m²	%	Lake 8 1982 No./m²	%
Mollusca	43	21	1238	51	559	60	1356	62	732	69	910	53
Diptera	14	7	348	14	157	17	560	26	151	14	243	14
Oligochaeta	72	36	754	31	186	20	248	11	107	10	474	27
Amphipoda	29	14	32	1	29	3	11	1	65	6	102	6
Others	43	21	44	2			22	1	11	1	5	<1
Total	201		2411		931		2196		1066		1728	
Number dredge hauls	3		4		3		4		4		8	
Number animals counted	14		224		65		204		99		321	
Total wet weight (g)	0.05		0.24		0.31		0.15		0.36		0.60	

Table 6. Comparison of densities of major benthic invertebrate taxa from sand and organic substrates in lakes of the Mayogiak and Freshwater Creek watersheds, 1982.

Lake	Density (No./m²) Mollusca Sand	Mollusca Detritus	Diptera Sand	Diptera Detritus	Oligochaeta Sand	Oligochaeta Detritus	Amphipoda Sand	Amphipoda Detritus	Total[1] Sand	Total[1] Detritus
Freshwater 1	ND	1238	ND	345	ND	754	ND	33	ND	2413
Freshwater 2	86	2626	194	927	86	409	0	22	366	4028
Freshwater 8	679	1131	162	324	87	862	162	43	1100	2359
Mayogiak 5	797	86	258	1464	108	366	0	65	1163	1981
Mean (No./m²)	521	1270	205	765	94	598	54	41	876	2695

[1] Includes other minor taxa.

Table 7. Summary of gillnetting results for lakes of the Mayogiak Creek watershed during 1981 and 1982[1].

Species	Lake 1 (1981 S)	Lake 2 (1981 S)	Lake 3 (1981 S)	Lake 5 (1982 W)	Total N	Total %
Broad whitefish	2	19	13		34	85
Lake whitefish	1				1	3
Least cisco	1				1	3
Northern pike				4	4	10
Total	4	19	13	4	40	

[1] S = Summer; W = Winter

Table 8. Summary of gillnetting results for lakes of the Freshwater Creek watershed during 1981 and 1982[1].

Species	Lake 1	Lake 2	Lake 3		Lake 6	Lake 8		Total	
	(1981S)	(1981S)	(1981S)	(1982W)	(1982S)	(1982S)	(1982W)	N	%
Broad whitefish	14	38	8	6	5	6	4	81	56
Lake whitefish	12	3				11	2	28	19
Least cisco		4	1		4	1	1	7	5
Northern pike			2			17	3	26	18
Burbot						2	1	3	2
Total	26	45	11	6	9	37	11	145	

[1] S = Summer; W = Winter

Table 9. Number of fish documented during the Freshwater Creek counting fence operation, 1982.

Species	Number of Fish	
	Upstream Trap	Downstream Trap
Broad whitefish	100 178	105 149
Lake whitefish	9 684	22 382
Least cisco	10 599	5 229
Northern pike	9	20
Lake trout	3	4
Ninespine stickleback	207	92
Pond smelt	26	53
Burbot		11
Total	120 706	132 940

Table 10. Mean fork length (mm), mean weight (g), mean condition factor (K), sex ratio, and maturity by age group for broad whitefish captured at the Freshwater Creek fence site, 1982.

Scale Age (yr)	Number of Fish	Fork Length			Weight			Mean Condition Factor (K)	Males		Females		Number Sex Unknown
		Mean	SD	Range	Mean	SD	Range		n	% Mature	n	% Mature	
0	17	68	8.5	56-81	3	1.5	1-6	0.97					17
1	49	133	29.3	79-194	27	20.1	2-77	0.96					49
2	19	199	15.8	174-226	86	26.2	50-140	1.06	1	0	5	0	13
3	34	242	29.7	191-298	166	86.1	72-350	1.07	6	0	10	0	18
4	29	274	29.8	225-324	247	102.3	90-440	1.13	11	0	12	0	6
5	35	319	31.4	243-358	408	126.1	150-600	1.21	10	0	22	0	3
6	19	342	40.6	270-418	507	207.9	160-1000	1.20	11	0	8	0	
7	25	377	26.2	329-451	703	191.6	440-1250	1.28	11	0	14	0	
8	15	401	25.1	370-477	874	214.3	625-1500	1.33	11	0	4	0	
9	17	410	47.8	312-527	925	398.9	310-2150	1.27	9	0	8	0	
10	23	479	42.4	399-568	1751	647.5	900-3400	1.52	14	7	9	33	
11	41	471	27.2	412-539	1581	345.9	810-2150	1.49	15	7	26	58	
12	20	505	49.1	394-584	2031	688.5	700-3625	1.51	10	0	10	70	
13	4	511	52.5	475-587	2019	649.5	1600-2975	1.48	2	0	2	50	
14	7	552	39.6	524-634	2094	747.7	1410-3425	1.22			6	33	1
15	3	477	28.5	448-505	1637	260.8	1350-1860	1.50	1	0	2	100	
16	2	548	46.0	515-580	2263	441.9	1950-2575	1.37	1	0	1	100	
17	1	558			2790			1.61			1	100	
18	1	445			1250			1.42	1	0			
Total	361								114		140		107

Table 11. Length-frequency distribution by age group for broad whitefish captured at the Freshwater Creek fence site, 1982.

Fork Length (mm)	Scale Age (yr)																			
	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	Total
50-74	12																			12
75-99	5	6																		11
100-124		16																		16
125-149		12																		12
150-174		12	1																	13
175-199		3	8	1																12
200-224			9	11																20
225-249			1	11	6	2														20
250-274				4	8	2	1													15
275-299				7	9	4	2													22
300-324					6	10	3			1										20
325-349						13	5	2		1										21
350-374						4	3	10	2	1										20
375-399							4	7	5	2	1		1							20
400-424							1	5	7	5		2	1							21
425-449										6	5	6	1			1			1	20
450-474								1			6	15	1							23
475-499									1		3	11	4	2		1				22
500-524											5	6	5	1	1	1	1			20
525-549										1	2	1	4		4					12
550-574											1		1		1			1		4
575-599													2	1			1			4
600-624															1					1
625-649																				
Total	17	49	19	34	29	35	19	25	15	17	23	41	20	4	7	3	2	1	1	361

Table 12. Length-weight regressions for broad whitefish in Freshwater Creek, 1982.

	n	Length Range (mm)	Slope (b)	y-Intercept (a)	SDb
Males					
Upstream	47	183-445	3.3210	-5.7452	0.0855
Downstream	111	255-577	3.3230	-5.7042	0.0302
Combined	158	183-577	3.4170	-5.9600	0.0321
Females					
Upstream	59	155-524	3.2379	-5.5422	0.0417
Downstream	123	269-587	3.2946	-5.6239	0.0495
Combined	182	155-587	3.3821	-5.8671	0.0320
All Combined[1]	719	56-634	3.2646	-5.5757	0.0111

[1] Includes unsexed fish

Table 13. Mean condition factors (K) for broad whitefish in different stages of migration in Freshwater Creek, 1982.

	Upstream - June		Downstream - July		Downstream - September	
	<425 mm	>425 mm	<425 mm	>425 mm	<425 mm	>425 mm
Mean K	1.2077	1.3546	1.2530	1.5358	1.3092	1.4809
Sample size	61	9	47	46	30	16
Mean fork length (mm)	365	445	346	505	295	490
Range in fork length (mm)	277-422	432-477	272-412	428-634	268-379	434-539
SD of K	0.0857	0.0950	0.0947	0.1476	0.0830	0.1015

Table 14. Seasonal changes in gonadosomatic index for female broad whitefish from Freshwater Creek, 1982, and from other locations in the Mackenzie Delta-Beaufort Sea area.

		July		August		September	
Location		1-15	16-31	1-15	16-31	1-15	16-30
Freshwater Creek (This study)	N	8	10	6	4		
	Mean	3.8	5.0	7.0	11.8		
	Range	2.6-5.8	3.5-6.5	3.3-10.7	9.8-12.2		
Tuktoyaktuk Harbour (Bond 1982)	N		7	12	1		
	Mean		4.9	7.3	9.5		
	Range		2.5-7.2	4.5-10.3			
Mackenzie River (1980-81) (K. Chang-Kue, Unpub. Data)	N		10	20		18	12
	Mean		5.8	7.3		15.7	19.6
	Range		4.0-7.8	4.9-9.4		8.2-22.4	15.8-22.8
All	N	8	27	38	5	18	12
	Mean	3.8	5.3	7.2	11.4	15.7	19.6
	Range	2.6-5.8	2.5-7.8	3.3-10.7	9.5-12.2	8.2-22.4	15.8-22.8

Table 15. Food habits of young-of-the-year broad whitefish captured at the Freshwater Creek fence site in September, 1982.

Food item	Percent Occurrence	Percent Number	Mean Number Per Stomach
Copepoda[1]	90.0	61.4	184.6
Cladocera[2]	93.3	38.3	115.1
Chironomidae	40.0	0.3	0.8
Trichoptera	3.3	<0.1	<0.1
No. stomachs examined	30		
No. stomachs empty	0		

[1] Mainly Epischura lacustris

[2] Mainly Bosmina longirostris

Table 16. Food habits of broad whitefish captured at the fence sites and in the lakes of the Mayogiak and Freshwater drainages, 1981-82. Results are expressed as estimated percentage composition by volume[1].

Food Category	Mayogiak			Freshwater		
	Fence Site		Lakes	Fence Site		Lakes
	Up	Down		Up	Down	
Diptera	60	53	14	31	16	9
Gastropoda			4	2	11	27
Pelecypoda			5	2	9	12
Amphipoda			30		2	5
Others	1	8	27	23	11	6
Digested Material	39	38	20	42	50	41
Number stomachs with food	69	11	31	26	40	70
Food points assigned (%)	602 (44)	65 (30)	388 (63)	170 (33)	205 (26)	725 (52)
Food points unassigned (%)	778 (56)	155 (70)	232 (37)	350 (67)	595 (74)	675 (48)

[1] Based on laboratory analyses and including only those stomachs that contained food.

Table 17. Mean fork length (mm), mean weight (g), mean condition factor (K), sex ratio, and maturity by age group for lake whitefish captured at the Freshwater Creek fence site, 1982.

Scale Age (yr)	Number of Fish	Fork Length			Weight			Mean Condition Factor (K)	Males		Females		Number Sex Unknown
		Mean	SD	Range	Mean	SD	Range		n	% Mature	n	% Mature	
0													
1	1	103			18			1.65					1
2	11	158	13.4	131-175	47	13.4	25-75	1.16	1	0	3	0	7
3	7	188	17.3	162-208	74	19.5	46-100	1.09	2	0	3	0	2
4	32	225	24.2	179-274	128	67.9	50-300	1.05	9	0	4	0	19
5	25	262	28.4	203-308	209	101.7	73-400	1.08	9	0	9	0	7
6	23	280	24.8	234-319	261	95.0	110-450	1.14	15	0	7	0	1
7	17	302	28.3	228-334	329	109.9	110-475	1.15	10	0	6	0	1
8	13	325	19.1	295-354	408	90.2	210-560	1.17	6	0	7	0	
9	15	354	14.5	331-380	554	84.4	410-725	1.24	9	0	6	0	
10	16	364	17.5	335-401	611	127.5	390-850	1.26	8	0	8	0	
11	8	374	31.8	348-437	729	324.0	450-1450	1.32	4	0	4	25	
12	4	385	21.0	354-400	775	136.3	640-950	1.36	1	0	3	33	
13	30	408	18.0	377-447	913	200.6	600-1410	1.33	15	0	15	27	
14	9	426	24.0	391-462	1052	233.0	750-1450	1.34	4	0	5	20	
15	10	443	19.8	414-485	1204	117.2	1050-1425	1.39	3	33	7	43	
16	8	432	31.9	376-469	1108	209.8	775-1460	1.38	2	0	6	33	
17	3	458	33.0	429-494	1457	305.0	1150-1760	1.50	2	0	1	100	
18	2	437	3.5	434-439	1113	17.7	1100-1125	1.34	1	0	1	0	
Total	234								101		95		38

Table 18. Length-frequency distribution by age group for lake whitefish captured at the Freshwater Creek fence site, 1982.

Fork Length (mm)	Scale Age (yr)																		
	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	Total
100-124		1																		1
125-149			4																	4
150-174			5	2																7
175-199			2	3	4															9
200-224				2	17	1														20
225-249					6	10	3	1												20
250-274					5	5	7	1												18
275-299						6	7	6	1											20
300-324						3	6	7	4											20
325-349								2	6	6	5	1								20
350-374									2	7	7	4	1							21
375-399										2	3	1	2	9	2		1			20
400-424											1	1	1	15	1	1	3			23
425-449												1		6	5	5	1	1	2	21
450-474															1	3	3	1		8
475-499																1		1		2
Total	0	1	11	7	32	25	23	17	13	15	16	8	4	30	9	10	8	3	2	234

Table 19. Length-weight regressions for lake whitefish in Freshwater Creek, 1982.

	n	Length Range (mm)	Slope (b)	y-Intercept (a)	SDb
Males					
Upstream	70	154-428	3.2357	-5.5290	0.0634
Downstream	67	156-469	3.5327	-6.2381	0.0897
Combined	137	154-469	3.3979	-5.9145	0.0546
Females					
Upstream	87	149-453	3.1356	-5.3952	0.0409
Downstream	48	274-494	3.2541	-5.5145	0.0780
Combined	135	149-494	3.2749	-5.6001	0.0381
All Combined[1]	389	103-494	3.2842	-5.6330	0.0261

[1] Includes unsexed fish

Table 20. Mean condition factors (K) for lake whitefish in different stages of migration in Freshwater Creek, 1982.

	Upstream - June		Downstream - July/August		Downstream - September	
	Males	Females	Males	Females	Males	Females
Mean K	1.2107	1.2449	1.3902	1.4942	1.2927	1.3174
Sample size	45	46	24	24	25	24
Mean fork length (mm)	360	378	401	416	332	344
Range in fork length (mm)	285-428	286-453	323-462	345-494	257-469	274-485
SD of K	0.0813	0.0793	0.1570	0.1361	0.1123	0.1283

Table 21. Seasonal changes in gonadosomatic index for female lake whitefish from Freshwater Creek, 1982, and from other locations in the Mackenzie Delta-Beaufort Sea area.

		July	August		September		October
Location		16-31	1-15	16-31	1-15	16-30	1-15
Freshwater Creek (This study)	N	4	5	2			
	Mean	4.0	6.1	8.0			
	Range	2.4-6.00	1.9-7.9	7.9-8.1			
Tuktoyaktuk Harbour (Bond 1982)	N	2	5		2		
	Mean	4.3	5.3		10.0		
	Range	3.3-5.2	4.3-6.6		7.5-12.4		
Mackenzie River (1981) (K. Chang-Kue, Unpub. Data)	N				16	16	5
	Mean				13.3	15.5	18.4
	Range				6.8-15.7	8.0-19.4	14.5-20.9
All	N	6	10	2	18	16	5
	Mean	4.1	5.7	8.0	11.9	15.5	18.4
	Range	2.4-6.0	1.9-7.9	7.9-8.1	6.8-15.7	8.0-19.4	14.5-20.9

Table 22. Food habits of lake whitefish captured at the fence sites and in the lakes of the Mayogiak and Freshwater drainages, 1981-82. Results are expressed as estimated percentage composition by volume[1].

Food Category	Mayogiak			Freshwater		
	Fence Site		Lakes	Fence Site		Lakes
	Up	Down		Up	Down	
Diptera	32	16	ND	20	4	5
Gastropoda		8		9	29	36
Pelecypoda				3	5	3
Amphipoda		26		4	12	3
Others	11	26		34	21	14
Digested Material	58	21		30	30	39
Number stomachs with food	6	2	ND	26	18	18
Food points assigned (%)	38 (32)	34 (85)		109 (21)	125 (35)	232 (64)
Food points unassigned (%)	82 (68)	6 (15)		411 (79)	235 (65)	128 (36)

[1] Based on laboratory analyses and including only those stomachs that contained food.

Table 23. Mean fork length (mm), mean weight (g), mean condition factor (K), sex ratio, and maturity by age group for least cisco captured at the Freshwater Creek fence site, 1982.

Scale Age (yr)	Number of Fish	Fork Length			Weight			Mean Condition Factor (K)	Males		Females		Number Sex Unknown
		Mean	SD	Range	Mean	SD	Range		n	% Mature	n	% Mature	
0	24	73	6.4	65-89	4	1.9	2-8	0.94					24
1	49	106	13.2	78-139	10	4.5	2-27	0.79					49
2	57	148	21.4	111-199	31	14.4	10-70	0.89	8	0	7	0	42
3	48	200	25.7	144-253	71	30.5	22-160	0.84	20	0	16	0	12
4	52	234	23.3	181-279	120	51.4	50-300	0.89	27	7	22	0	3
5	27	263	25.6	231-340	181	86.5	100-510	0.94	14	21	13	15	
6	26	296	17.2	263-351	274	70.3	175-490	1.05	17	41	9	22	
7	35	314	19.2	290-368	343	81.4	210-600	1.09	16	69	19	26	
8	37	321	18.7	291-368	347	110.6	200-650	1.02	8	38	29	41	
9	25	333	23.9	308-383	389	102.8	225-640	1.04	3	33	22	50	
10	4	333	2.4	330-335	338	47.9	300-400	0.91			4	0	
11	1	366			560			1.14			1	100	
Total	385								113		142		130

Table 24. Length-frequency distribution by age group for least cisco captured at the Freshwater Creek fence site, 1982.

Fork Length (mm)	Scale Age (yr)												
	0	1	2	3	4	5	6	7	8	9	10	11	Total
50-74	16												16
75-99	8	15											23
100-124		31	8										39
125-149		3	25	1									29
150-174			15	7									22
175-199			9	17	5								31
200-224				15	11								26
225-249				5	21	7							33
250-274				3	13	14	1						31
275-299					2	3	19	11	3				38
300-324						2	4	16	20	11			53
325-349						1	1	7	9	9	4		31
350-374							1	1	5	2		1	10
375-399										3			3
Total	24	49	57	48	52	27	26	35	37	25	4	1	385

Table 25. Length-weight regressions for least cisco in Freshwater Creek, 1982.

	n	Length Range (mm)	Slope (b)	y-Intercept (a)	SDb
Males					
Upstream	77	150-383	3.3214	-5.8063	0.0944
Downstream	37	196-351	3.5461	-6.3182	0.1693
Combined	114	150-383	3.4232	-6.0387	0.0779
Females					
Upstream	85	155-383	3.2839	-5.7302	0.0803
Downstream	59	173-378	3.4407	-6.0757	0.1068
Combined	144	155-383	3.3943	-5.9821	0.0621
All Combined[1]	429	65-383	3.1700	-5.4318	0.0203

[1] Includes unsexed fish

Table 26. Mean condition factors (K) for least cisco in different stages of migration in Freshwater Creek, 1982.

	Upstream (June - July)	Downstream (July - August)	Downstream (September)
Mean K	0.8738	1.0636	1.0412
Sample size	84	48	48
Mean fork length (mm)	274	306	286
Range in fork length (mm)	155-383	214-366	173-378
SD of K	0.1663	0.1394	0.1587

Table 27. Seasonal changes in gonadosomatic index for female least cisco in the Mackenzie Delta-Beaufort Sea area.

Location		July 1-15	July 16-31	August 1-15	August 16-31	September 1-15	September 16-31	October 1-15
Freshwater Creek (This study)	Mean	1.5	2.1	6.8	8.8	9.8		
	Range	0	0	4.5-8.5	6.9-10.7	5.3-17.7		
	N	1	1	4	16	9		
Mackenzie River (1981) (K. Chang-Kue, Unpub. Data)	Mean					11.0	13.3	14.4
	Range					4.9-14.3	10.8-18.4	9.3-20.3
	N					15	6	25
All	Mean	1.5	2.1	6.8	8.8	10.6	13.3	14.4
	Range	0	0	4.5-8.5	6.9-10.7	4.9-17.7	10.8-18.4	9.3-20.3
	N	1	1	4	16	24	6	25

Table 28. Food habits of least cisco captured at the Freshwater Creek fence site, 1982. Results are expressed as frequency of occurrence (FO), percentage composition by number (%N), and estimated percentage composition by volume[1].

Food Item	Upstream FO	Upstream %N	Upstream % Vol.	Downstream FO	Downstream %N	Downstream % Vol.
Crustacea						
Cladocera	64.9	92.4	40.3	86.5	97.4	64.2
Copepoda	37.8	6.3	3.8	27.0	1.7	12.9
Ostracoda				32.4	0.9	1.1
Amphipoda	2.7	<0.1	0.8			
Diptera						
Chironomidae larvae	27.0	0.1	1.3	10.8	<0.1	1.3
pupae	8.1	<0.1	1.3	5.4	<0.1	0.4
Simuliidae larvae	16.2	0.9	11.0	2.7	<0.1	0.2
pupae	13.5	0.1	1.9			
adults	16.2	0.2	7.0			
Plecoptera	5.4	<0.1	0.5	5.4	<0.1	2.7
Coleoptera				2.7	<0.1	0.7
Trichoptera				13.5	<0.1	3.1
Acarina	2.7	<0.1	0.3	10.8	<0.1	0.2
Araneae				5.4	<0.1	0.7
Nematoda				5.4	<0.1	0.4
Fish (Stickleback)	8.1	<0.1	22.6			
Digested Matter	81.1		9.1	89.2		12.0
Number stomachs examined		37			37	
Total food points assigned (%)		372 (50.3)			450 (60.8)	
Total food points unassigned (%)		368 (49.7)			290 (39.2)	

[1] Based on laboratory analyses and including only those stomachs that contained food.

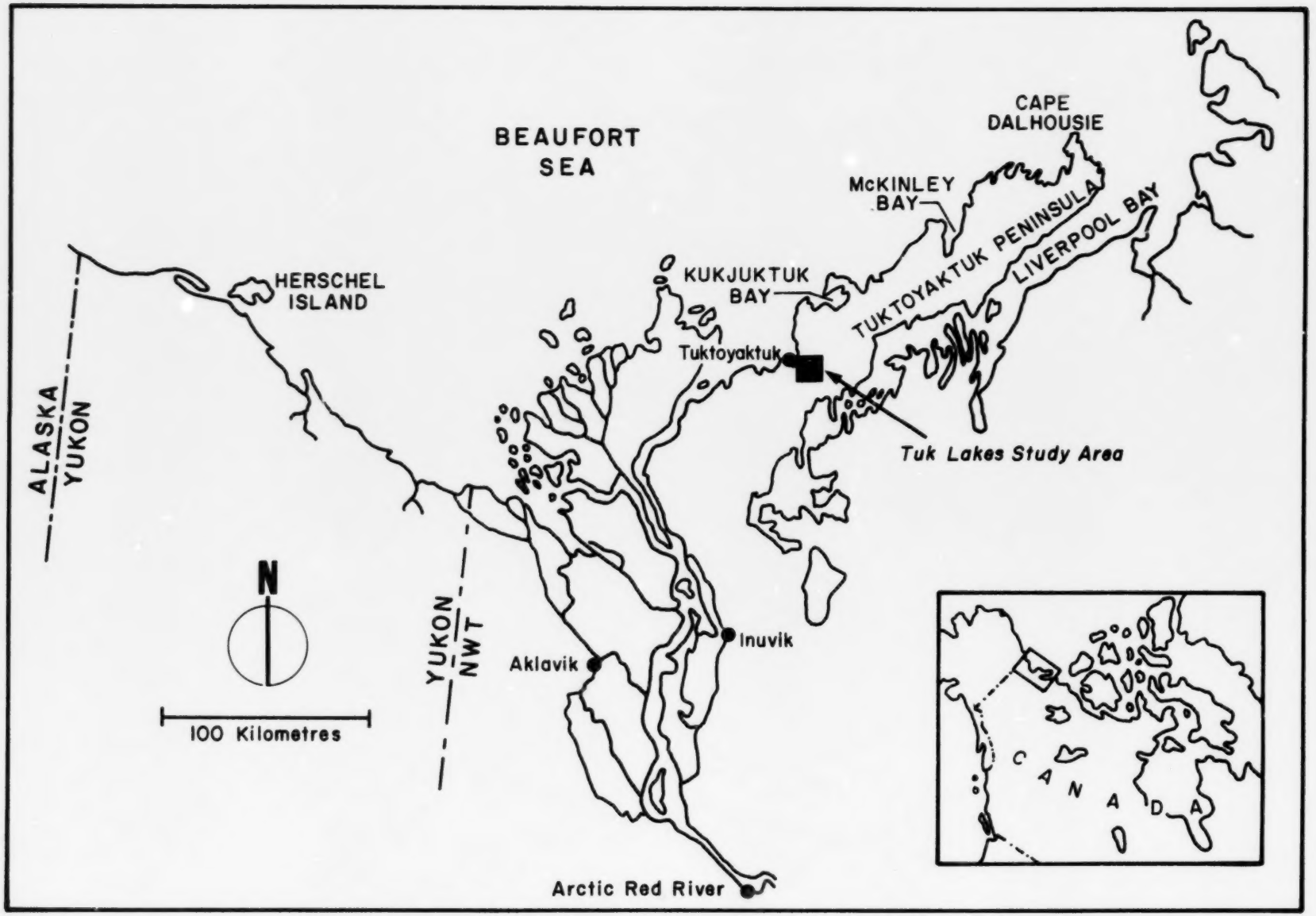

Fig. 1. The Mackenzie Delta and southern Beaufort Sea showing the location of the study area.

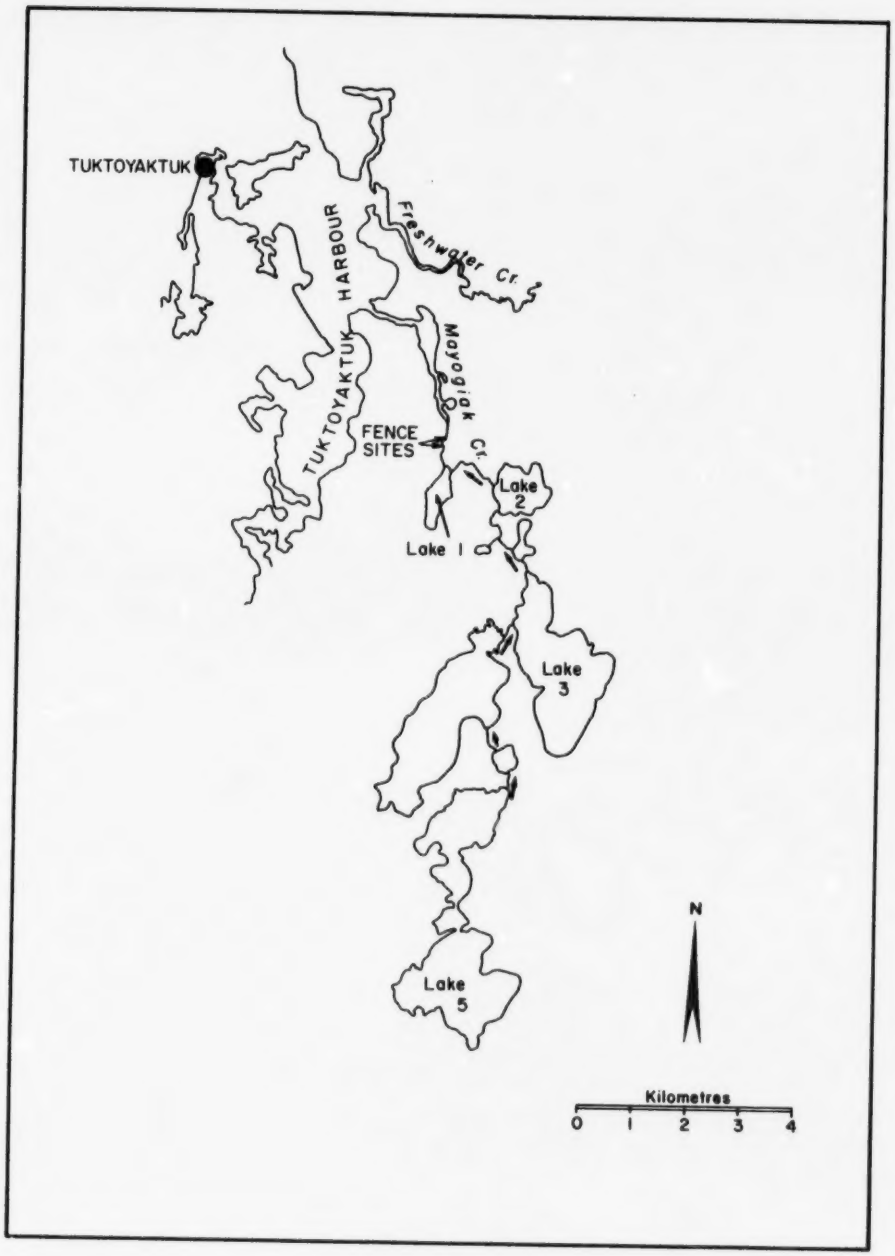

Fig. 2. The Mayogiak Creek watershed indicating the location of the counting fence and the lakes surveyed in 1981-1982.

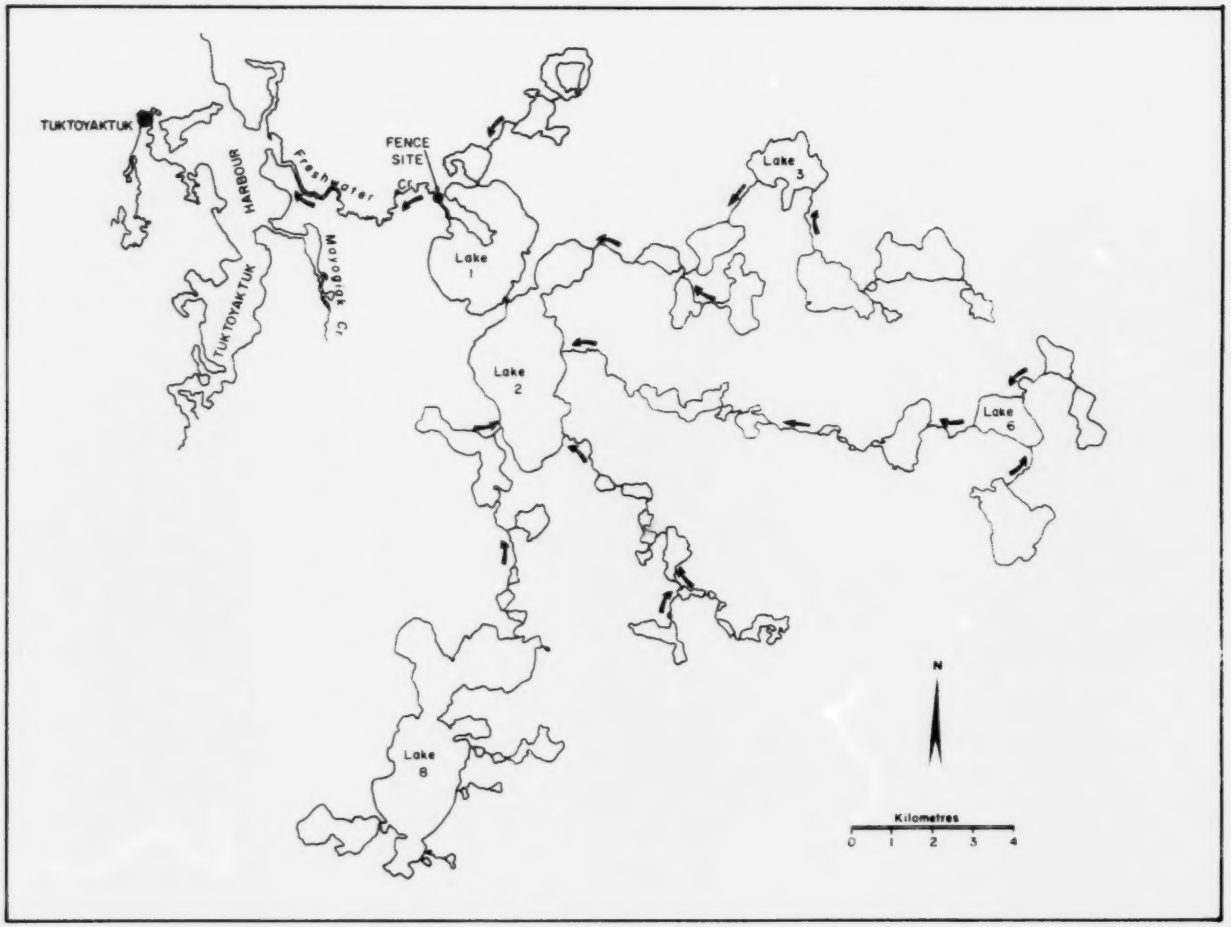

Fig. 3. The Freshwater Creek watershed indicating the location of the counting fence and the lakes surveyed in 1981-1982.

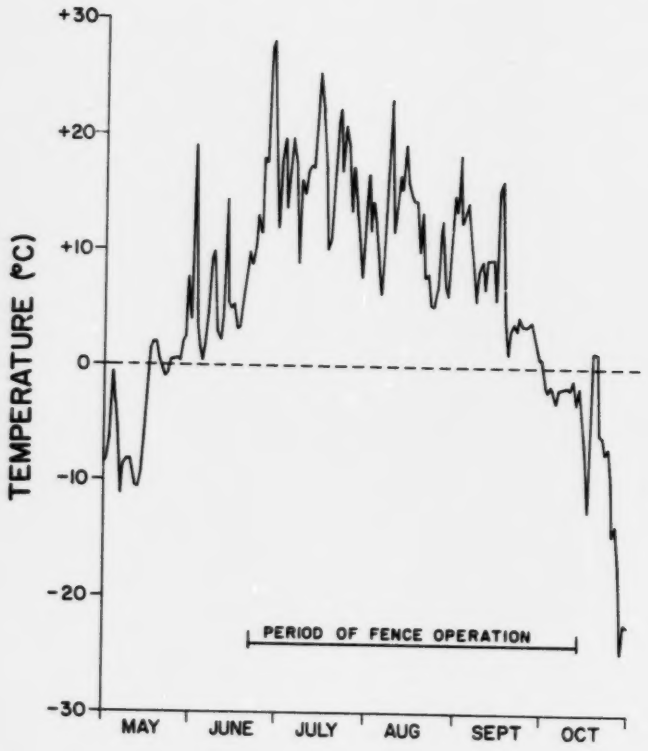

Fig. 4. Maximum daily air temperatures recorded at Tuktoyaktuk, 1 May - 31 October 1982, by the Atmospheric Environment Service, Environment Canada.

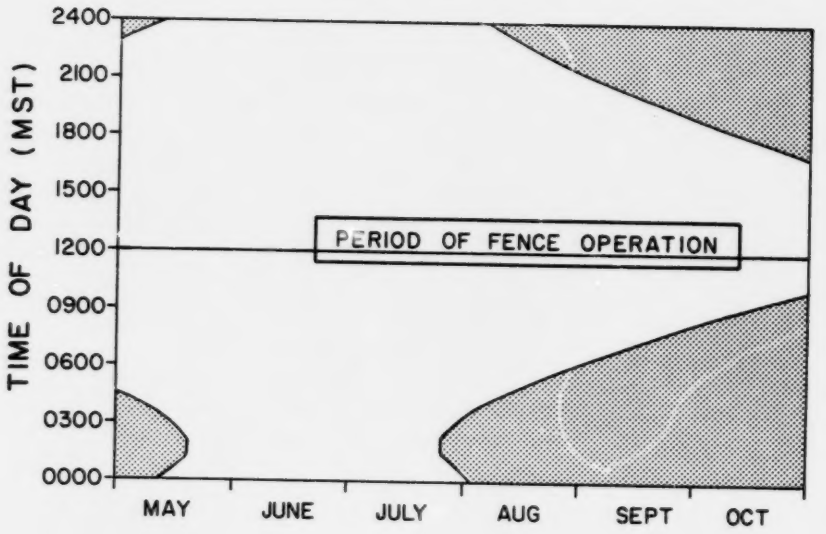

Fig. 5. Times of sunrise and sunset recorded at Tuktoyaktuk, 1 May - 31 October 1982, by the Atmospheric Environment Service, Environment Canada. (Stippled area indicates time sun was below the horizon.)

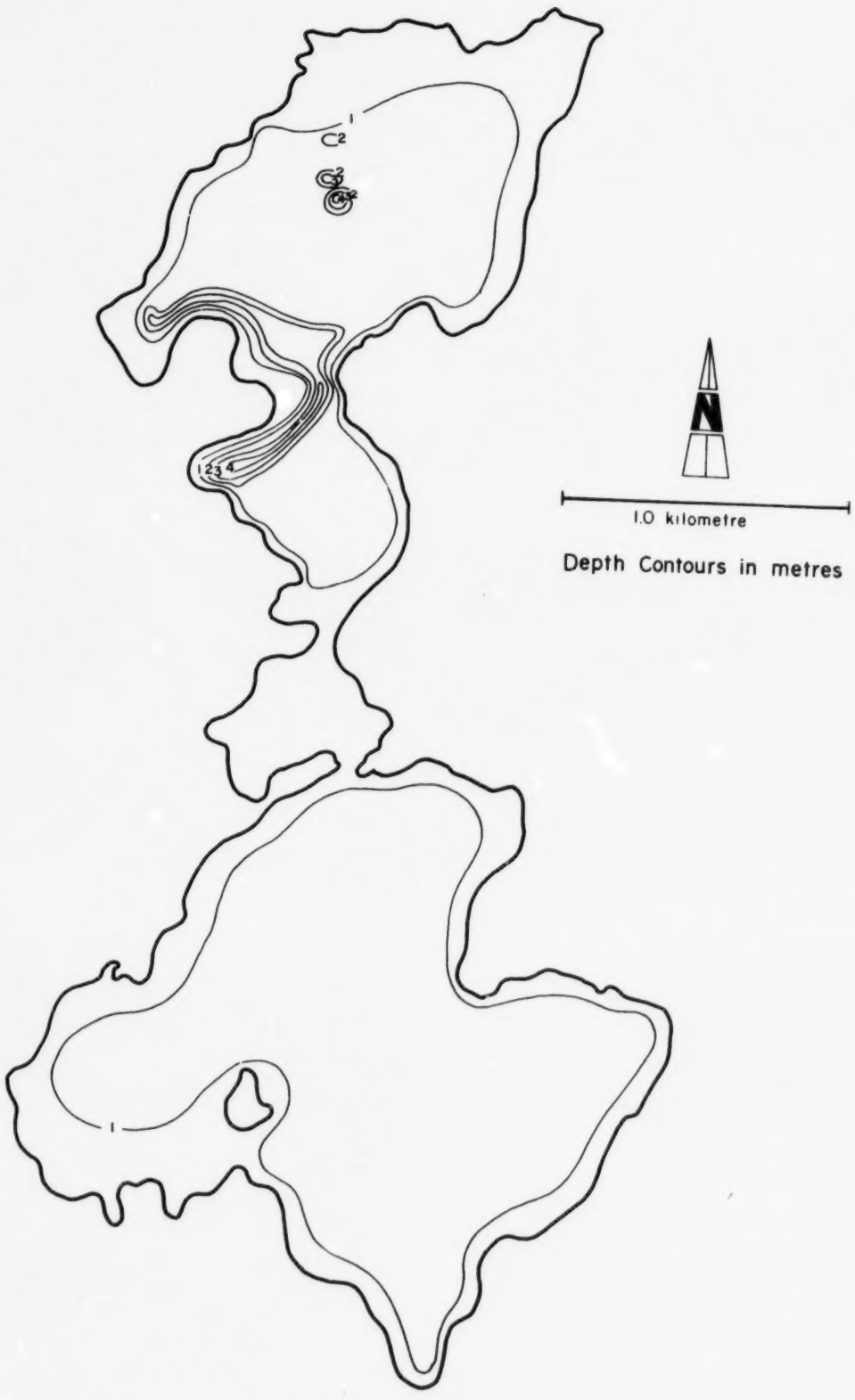

Fig. 6. Bathymetric map of Mayogiak Lake 5.

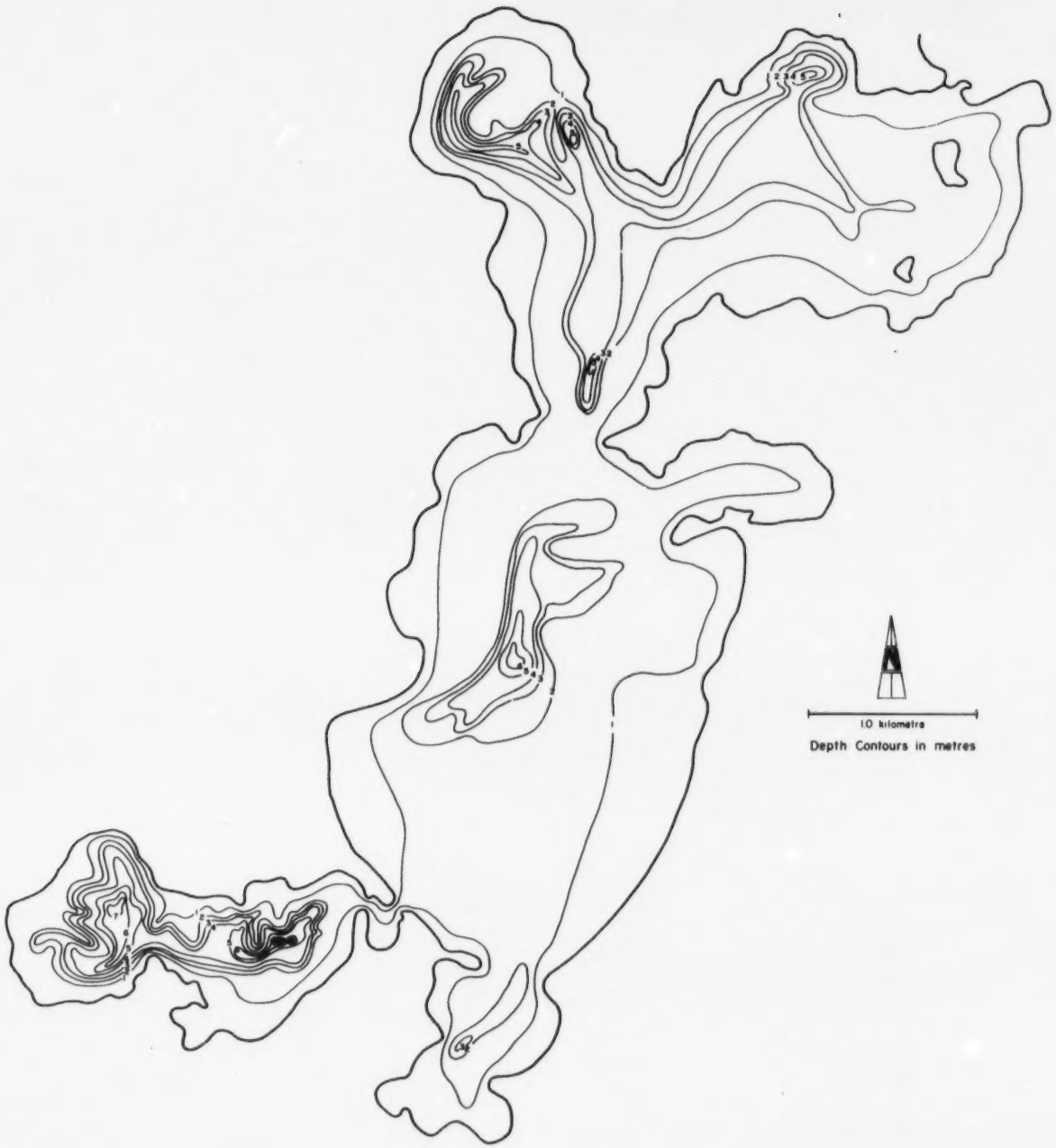

Fig. 7. Bathymetric map of Freshwater Lake 8.

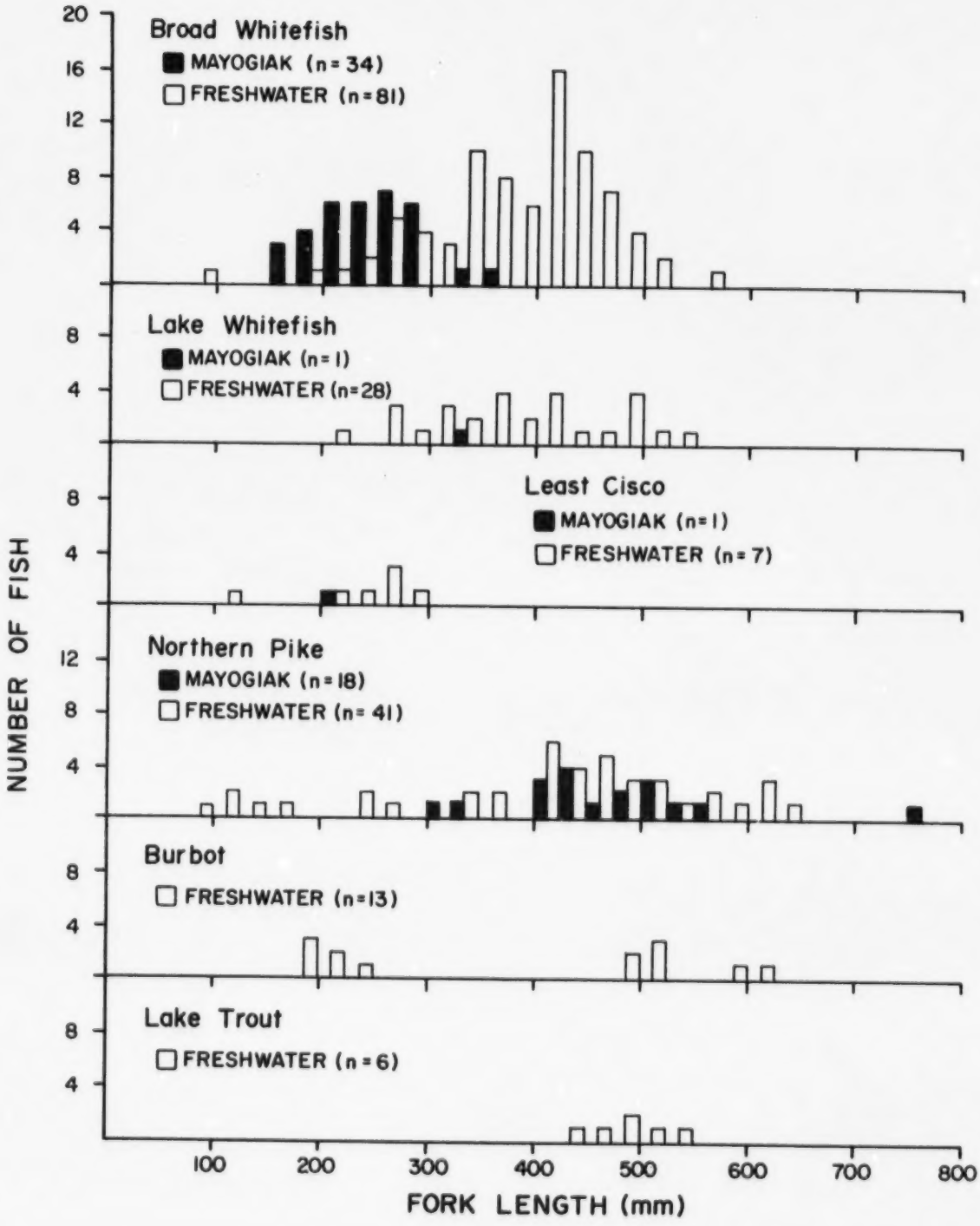

Fig. 8. Length-frequency distributions for fish captured by gillnet in lakes of the Mayogiak and Freshwater drainages, 1981-1982.

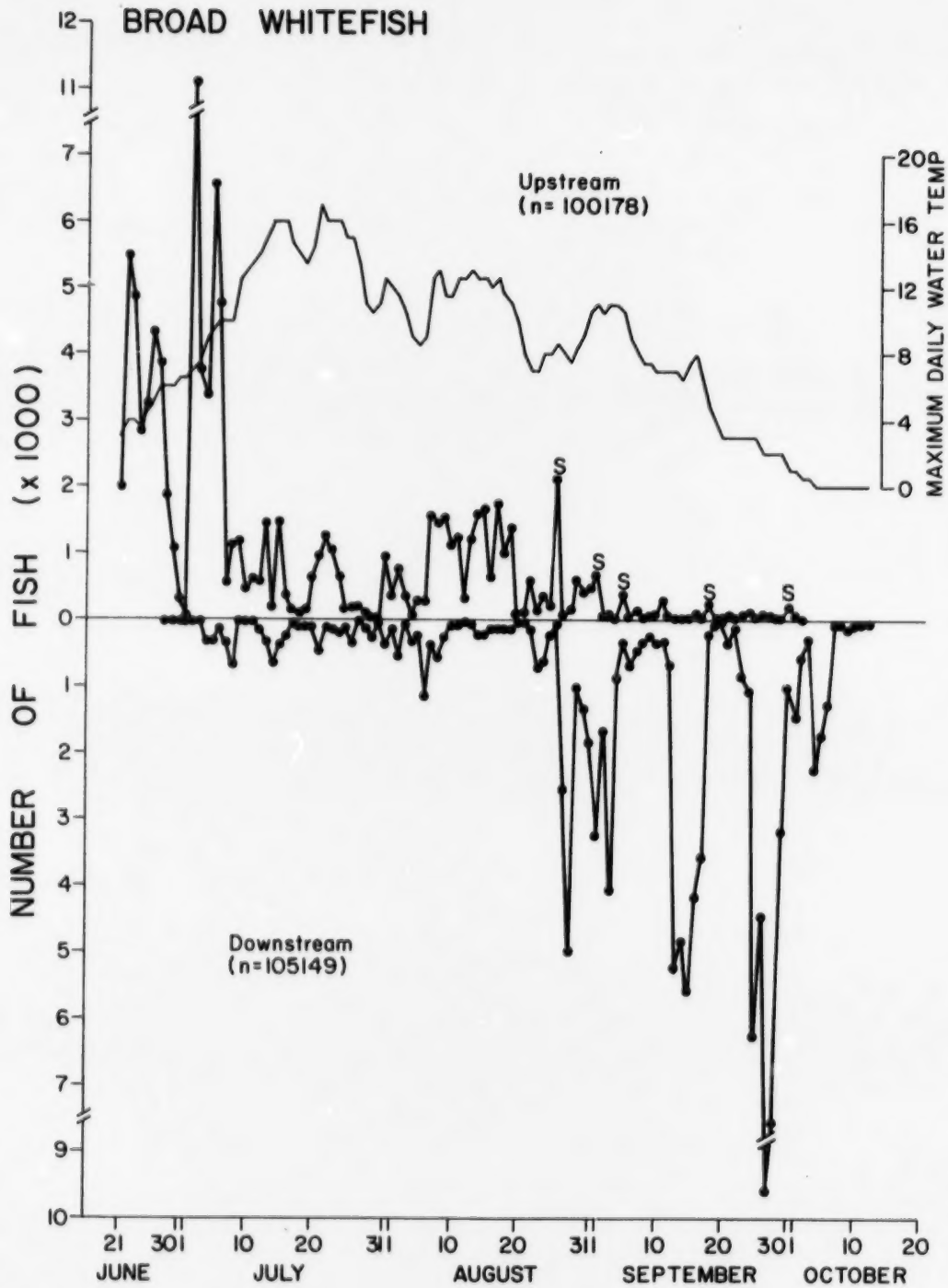

Fig. 9. Number of broad whitefish captured each day in upstream and downstream traps at Freshwater Creek, 1982. (S indicates that seined fish were included in daily total.)

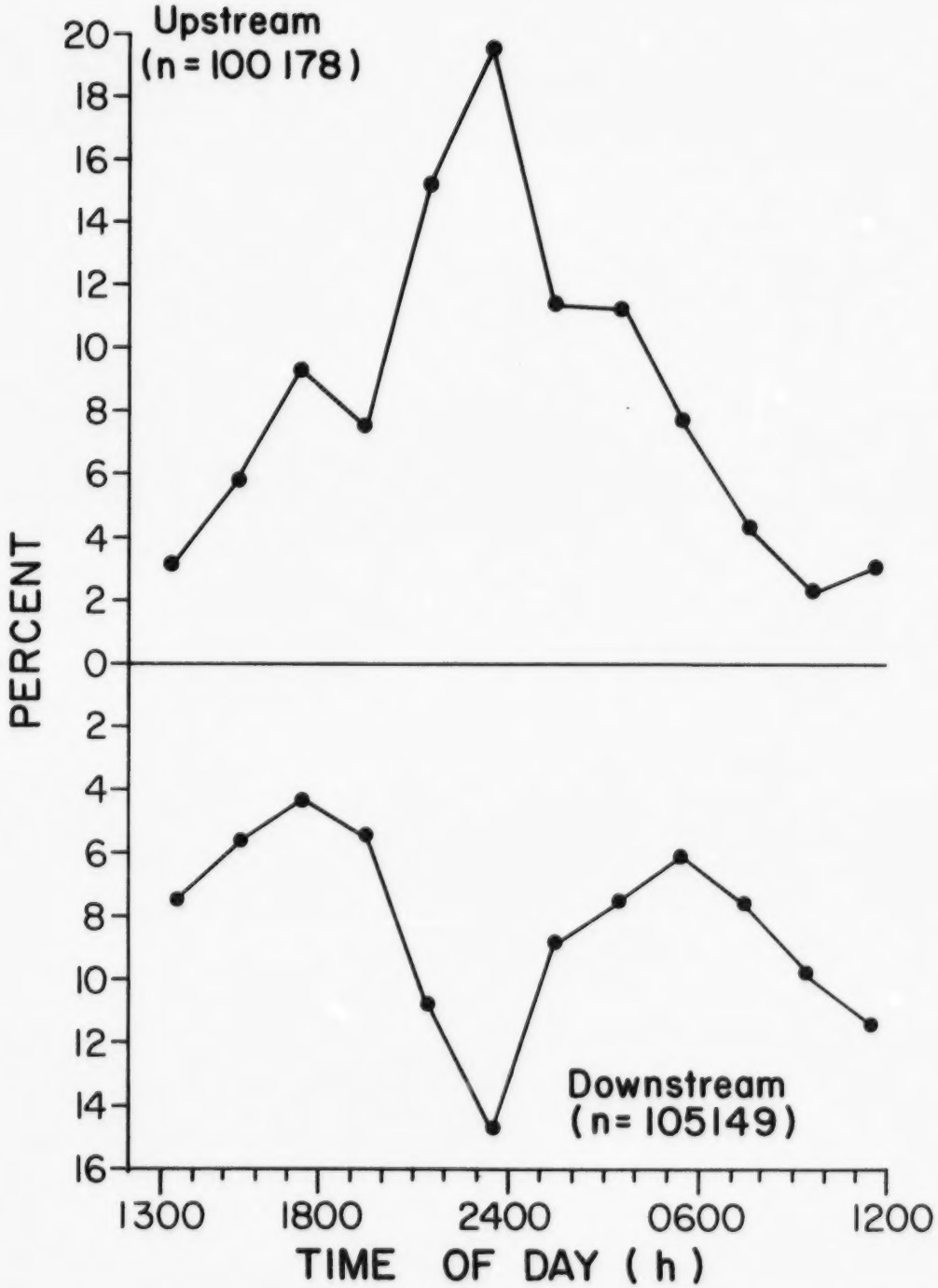

Fig. 10. Diel timing of the upstream and downstream migrations of broad whitefish in Freshwater Creek, 1982.

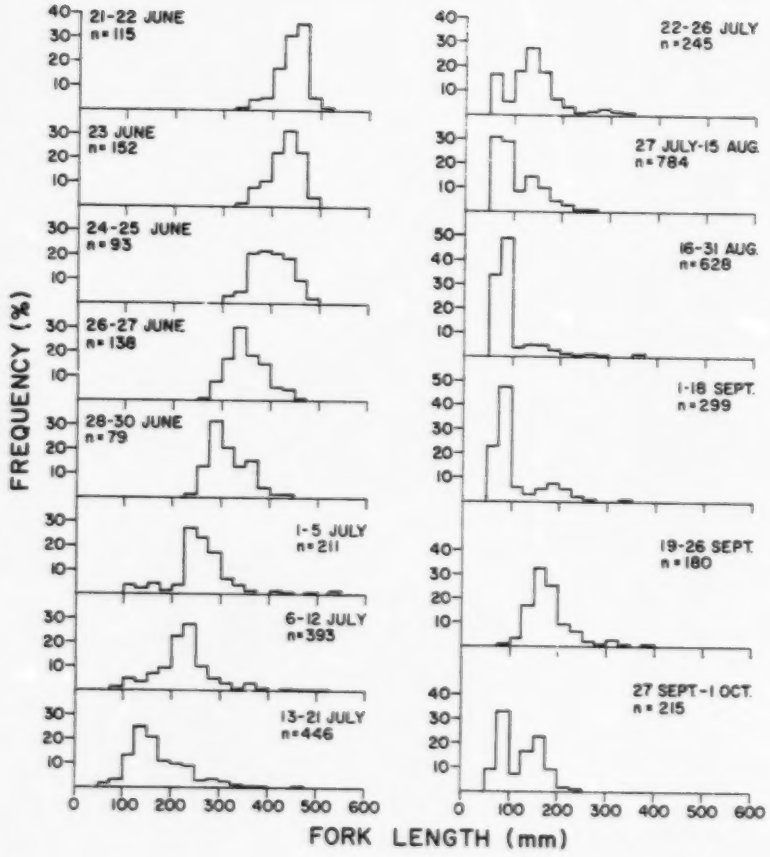

Fig. 11. Length-frequency distribution for broad whitefish measured during different segments of the upstream migration in Freshwater Creek, 1982.

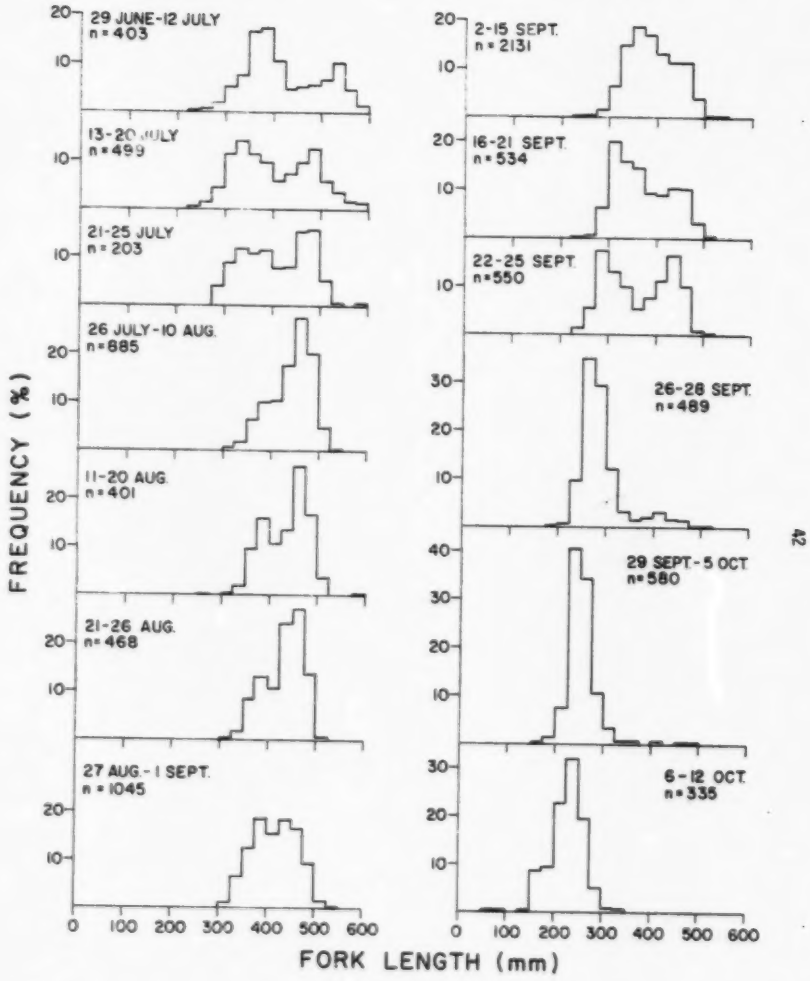

Fig. 12. Length-frequency distribution for broad whitefish measured during different segments of the downstream migration in Freshwater Creek, 1982.

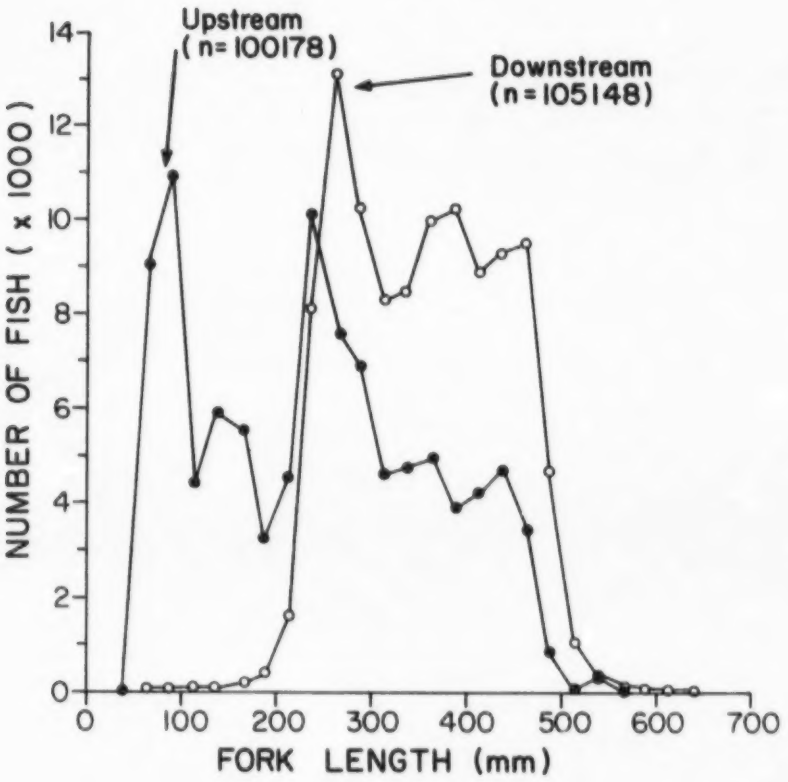

Fig. 13. Estimated overall length-frequency distributions for broad whitefish in the upstream and downstream migrations in Freshwater Creek, 1982.

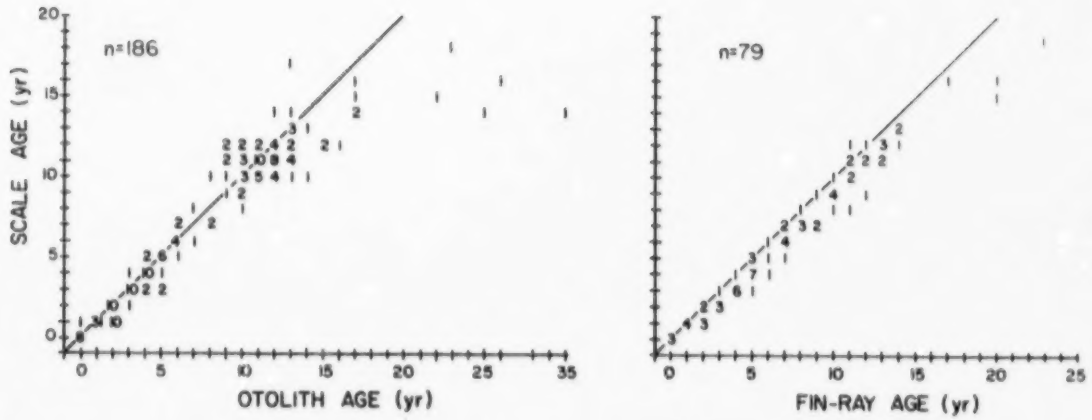

Fig. 14. Comparison of scale age:otolith age and scale age:fin-ray age pairs for broad whitefish from Freshwater Creek, 1982.

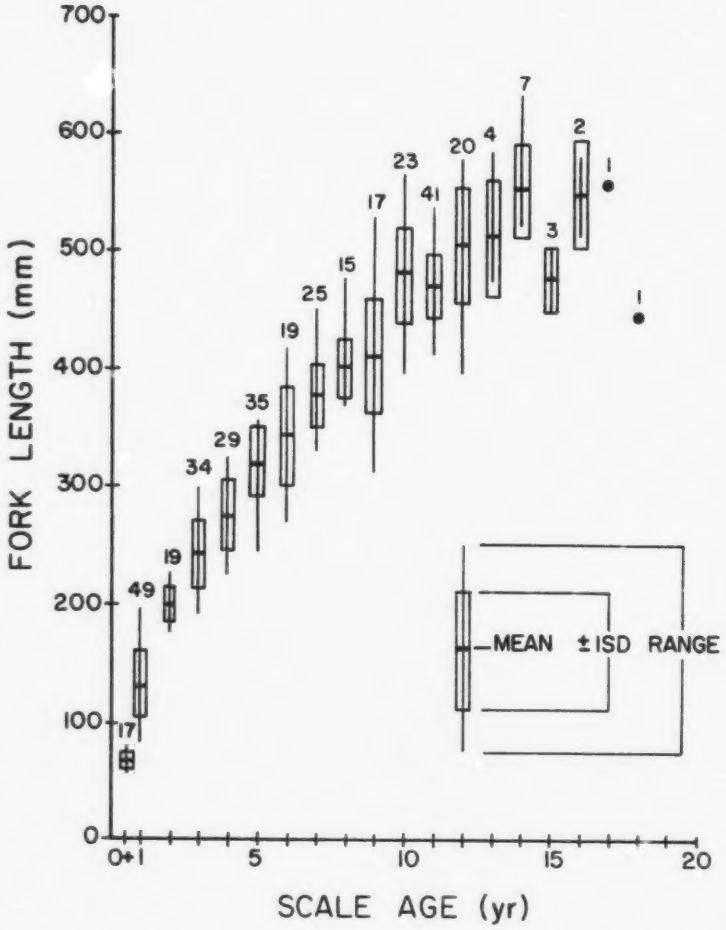

Fig. 15. Growth in fork length for broad whitefish captured in Freshwater Creek, 1982.

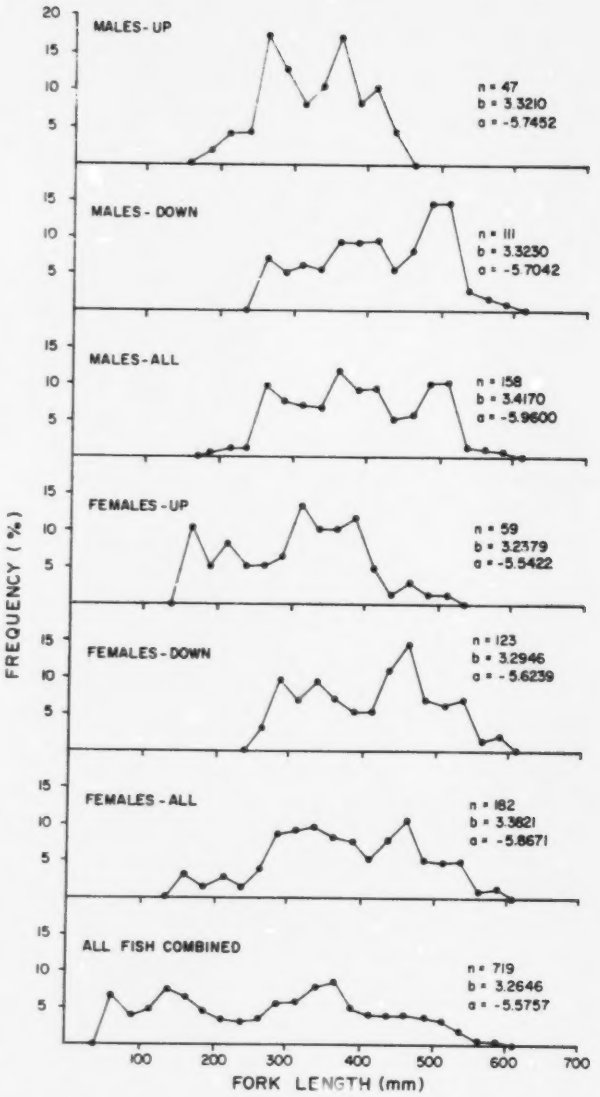

Fig. 16. Length-frequency distributions for samples of broad whitefish used in length-weight regression analysis, Freshwater Creek, 1982

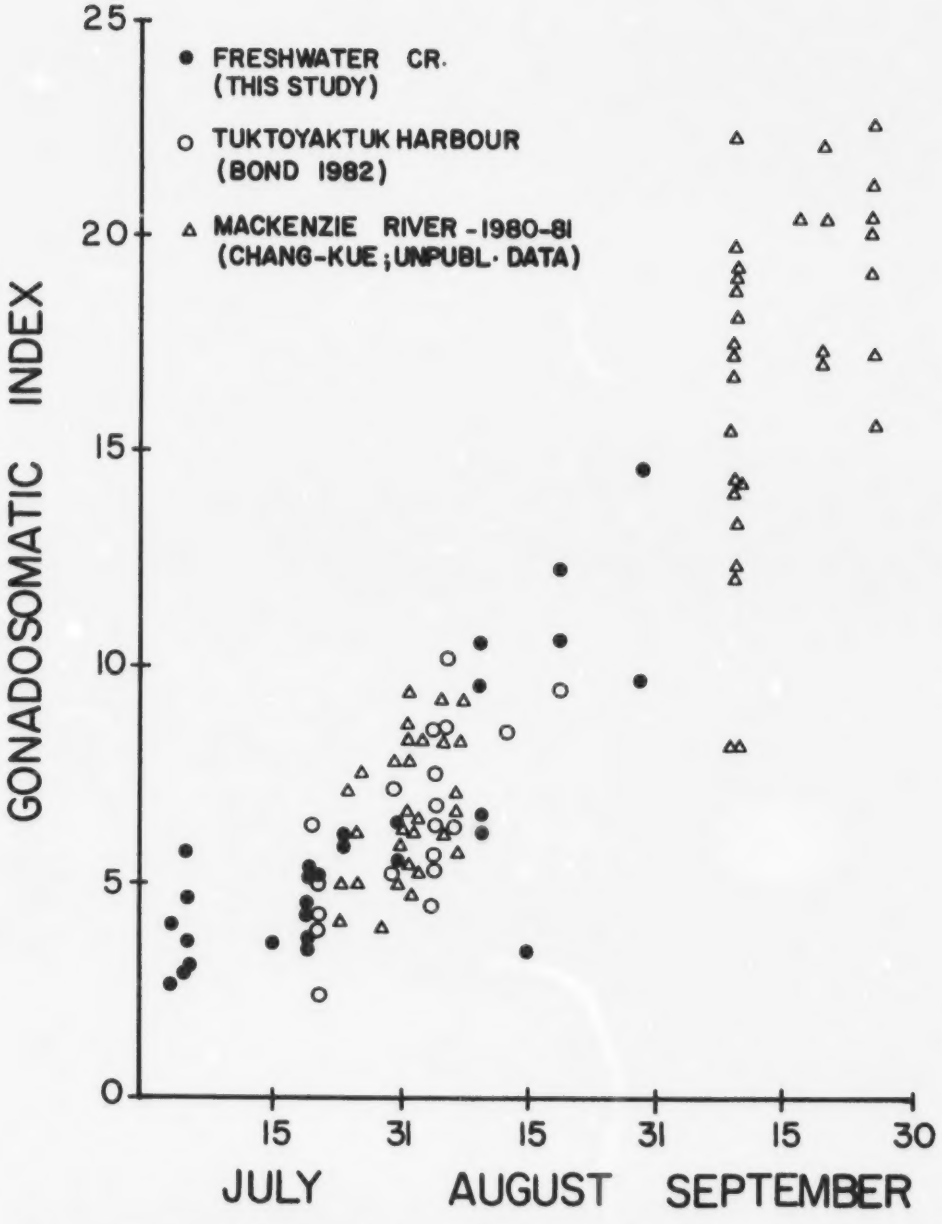

Fig. 17. Gonadosomatic index values recorded for mature female broad whitefish during the summer at Freshwater Creek, 1982 and elsewhere in the Mackenzie Delta-Beaufort Sea area.

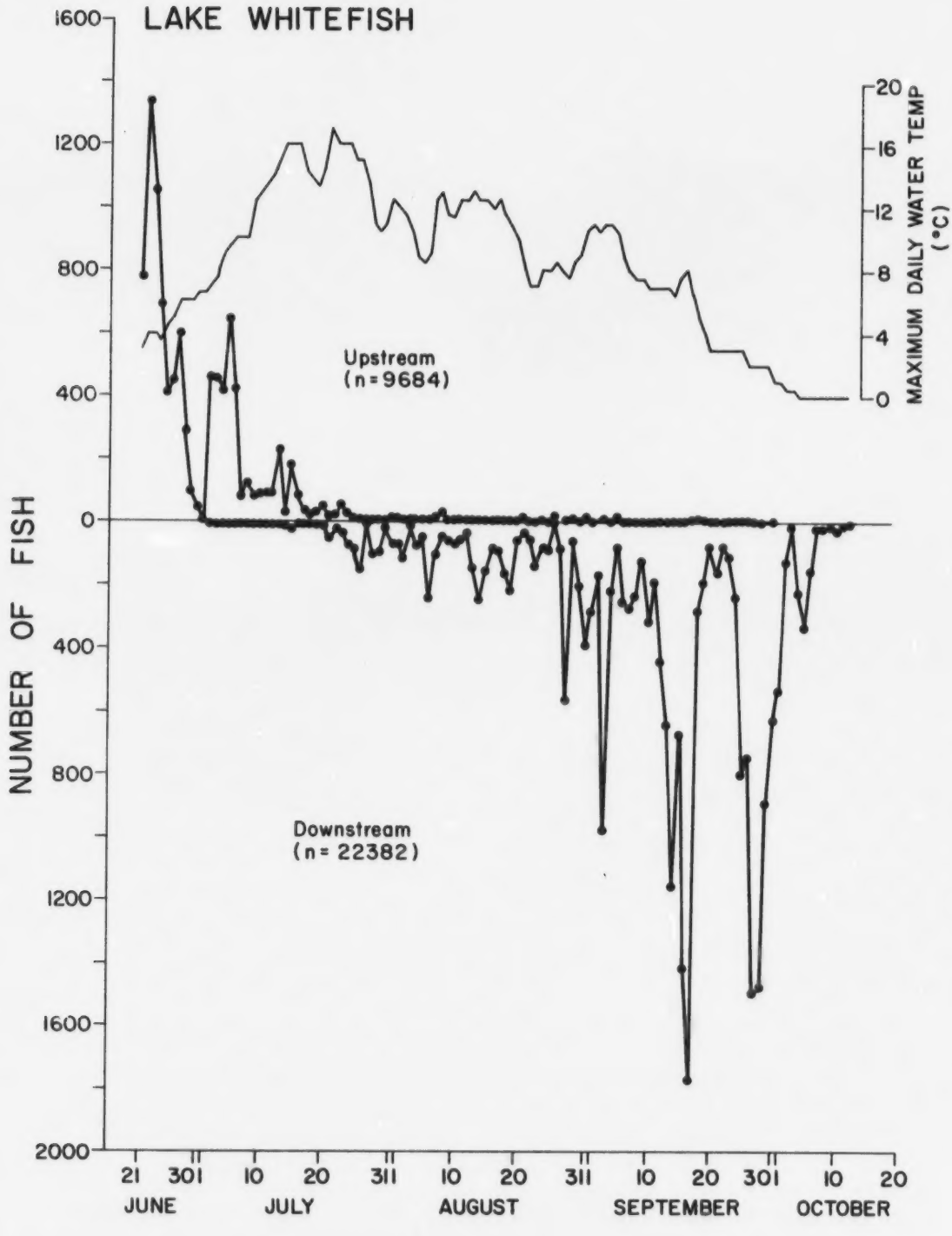

Fig. 18. Number of lake whitefish captured each day in upstream and downstream traps at Freshwater Creek, 1982.

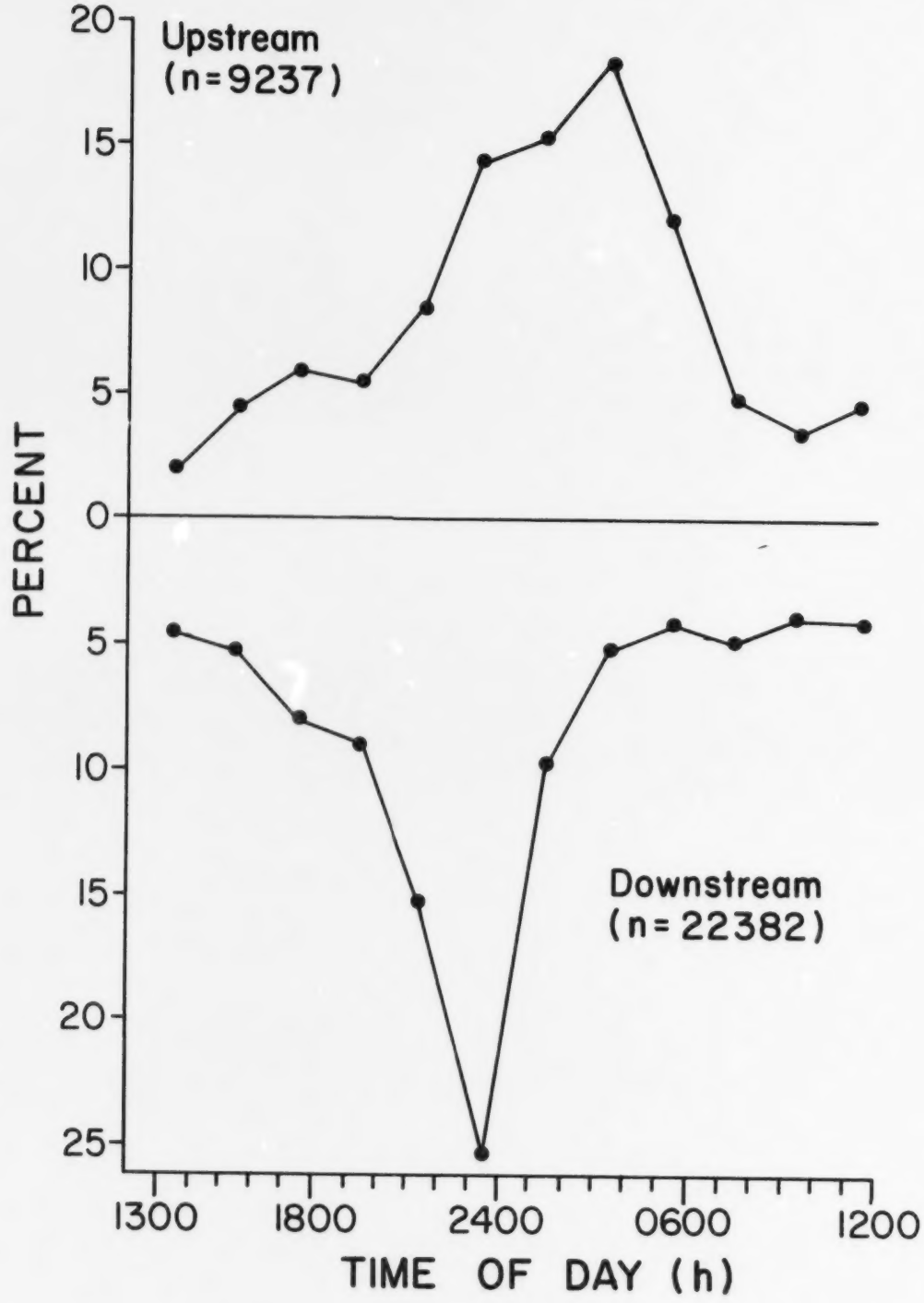

Fig. 19. Diel timing of the upstream and downstream migrations of lake whitefish in Freshwater Creek, 1982.

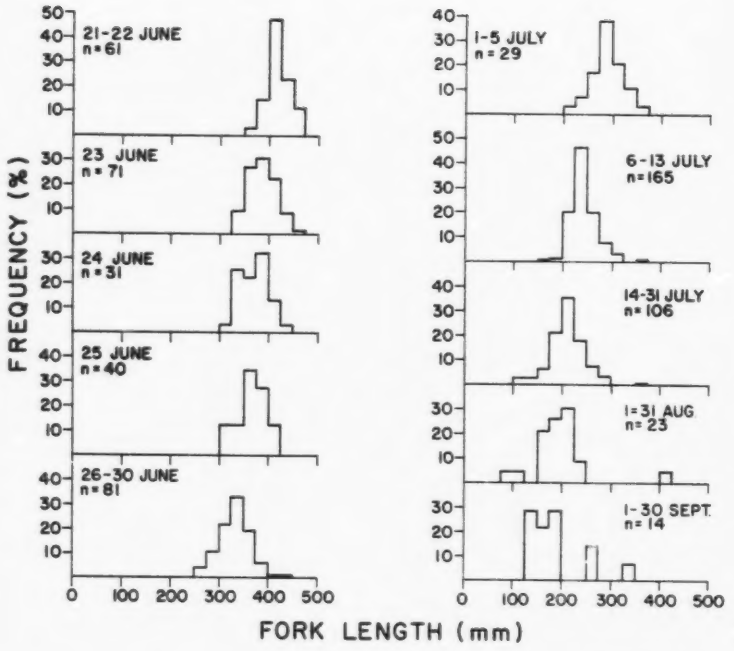

Fig. 20. Length-frequency distribution for lake whitefish measured during different segments of the upstream migration in Freshwater Creek, 1982.

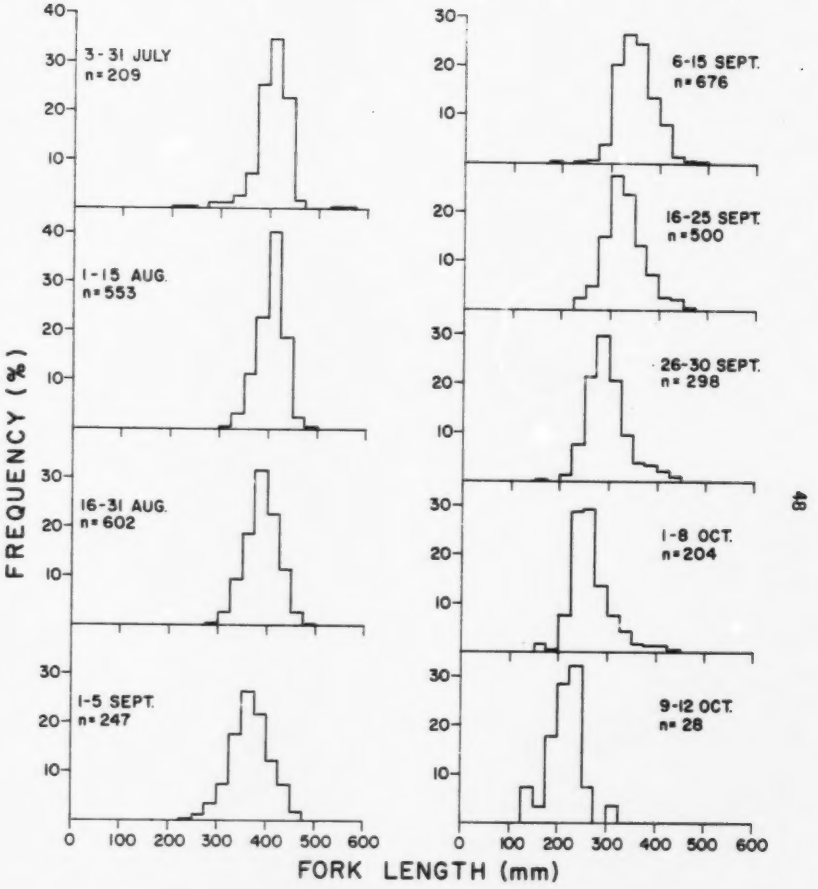

Fig. 21. Length-frequency distribution for lake whitefish measured during different segments of the downstream migration in Freshwater Creek, 1982.

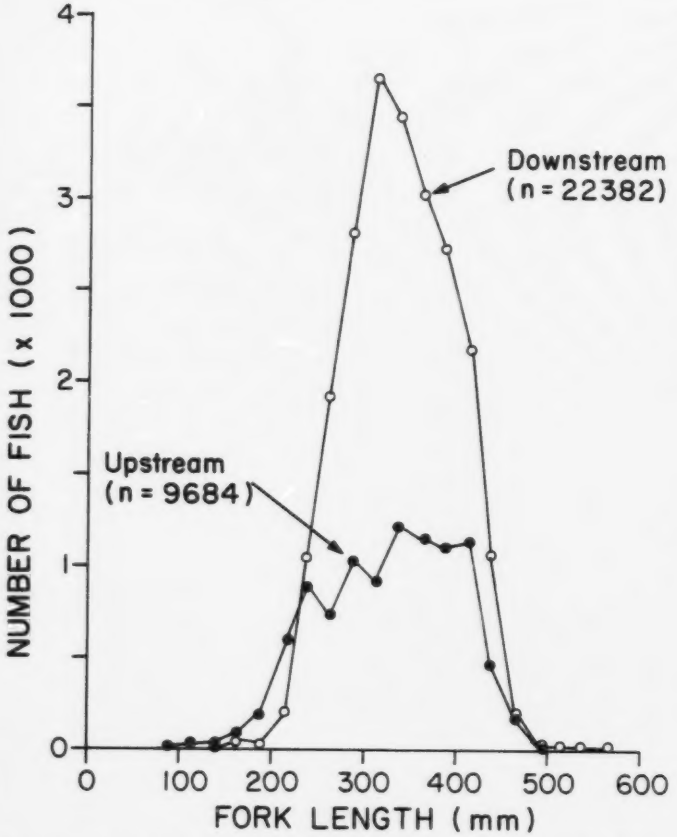

Fig. 22. Estimated overall length-frequency distributions for lake whitefish in the upstream and downstream migrations in Freshwater Creek, 1982.

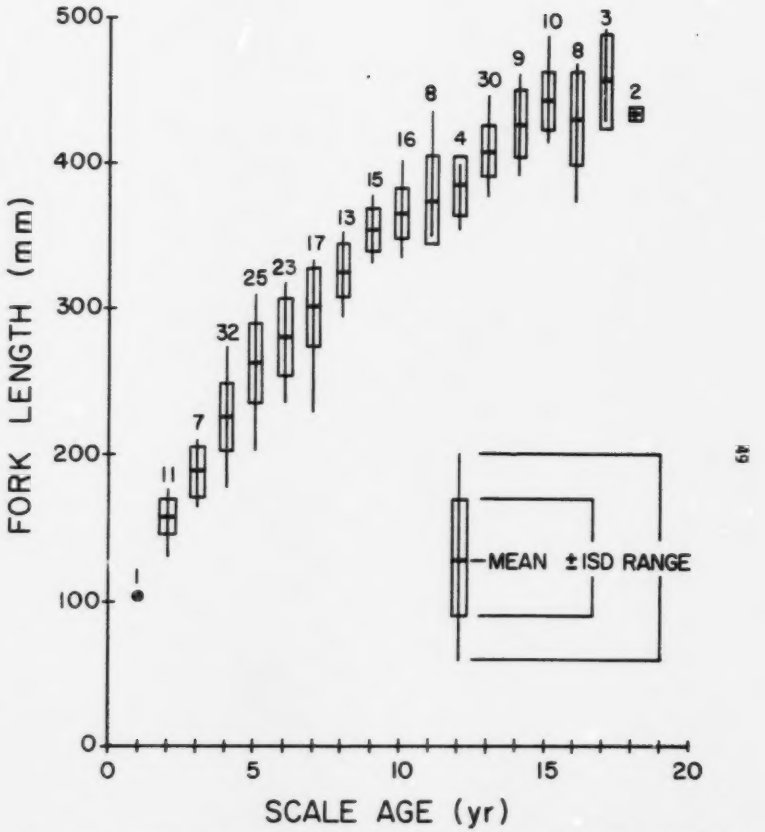

Fig. 23. Growth in fork length for lake whitefish captured in Freshwater Creek, 1982.

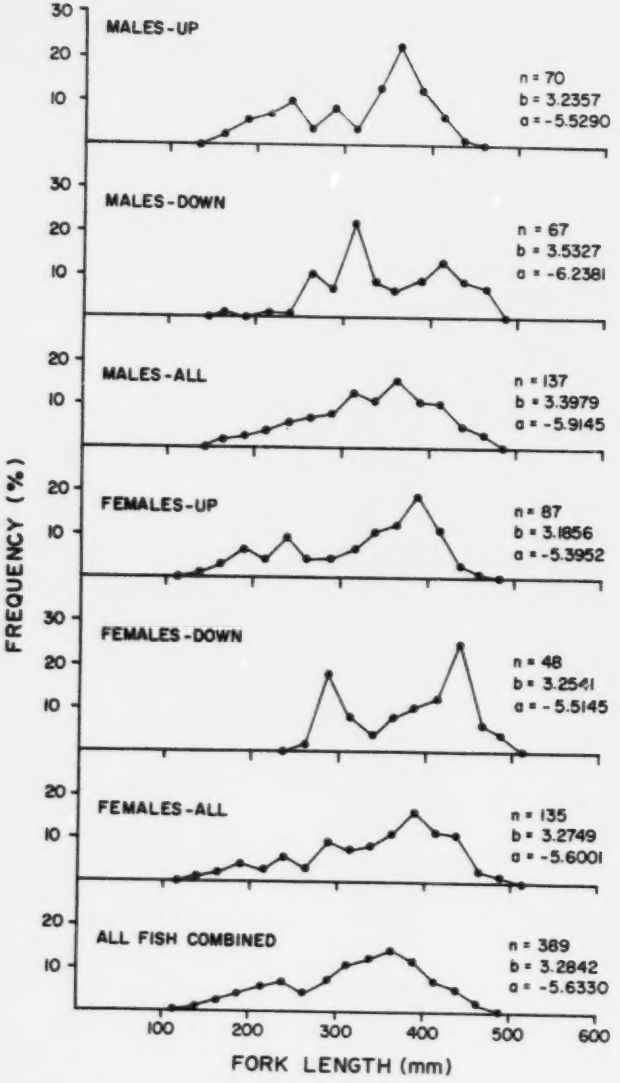

Fig. 24. Length-frequency distributions for samples of lake whitefish used in length-weight regression analysis, Freshwater Creek, 1982.

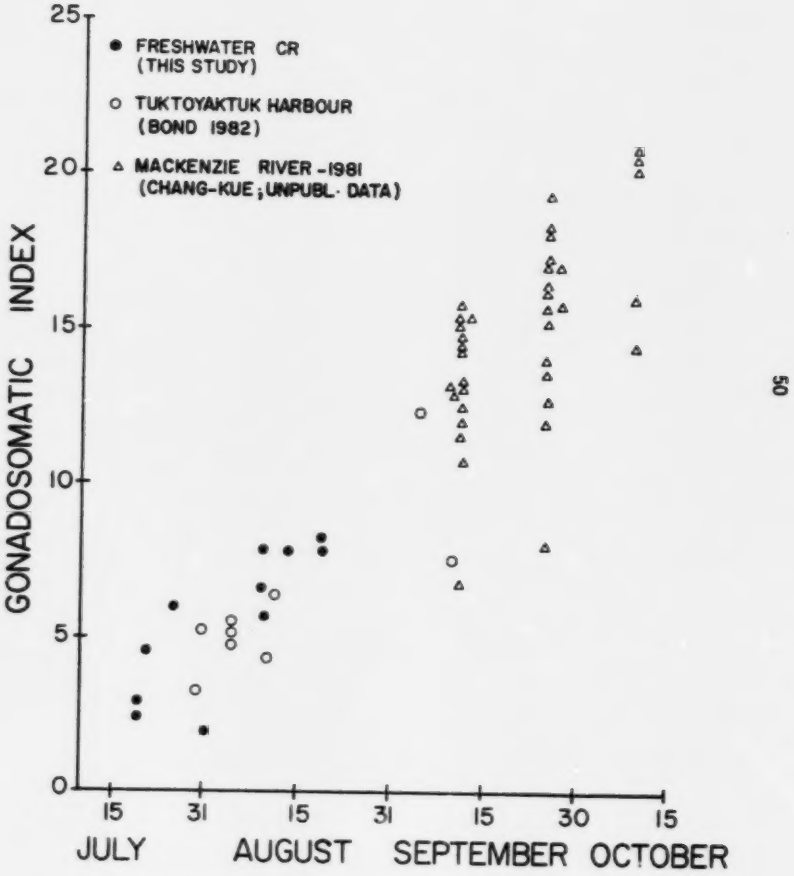

Fig. 25. Gonadsomatic index values recorded for mature female lake whitefish during the summer at Freshwater Creek 1982 and elsewhere in the Mackenzie Delta-Beaufort Sea area.

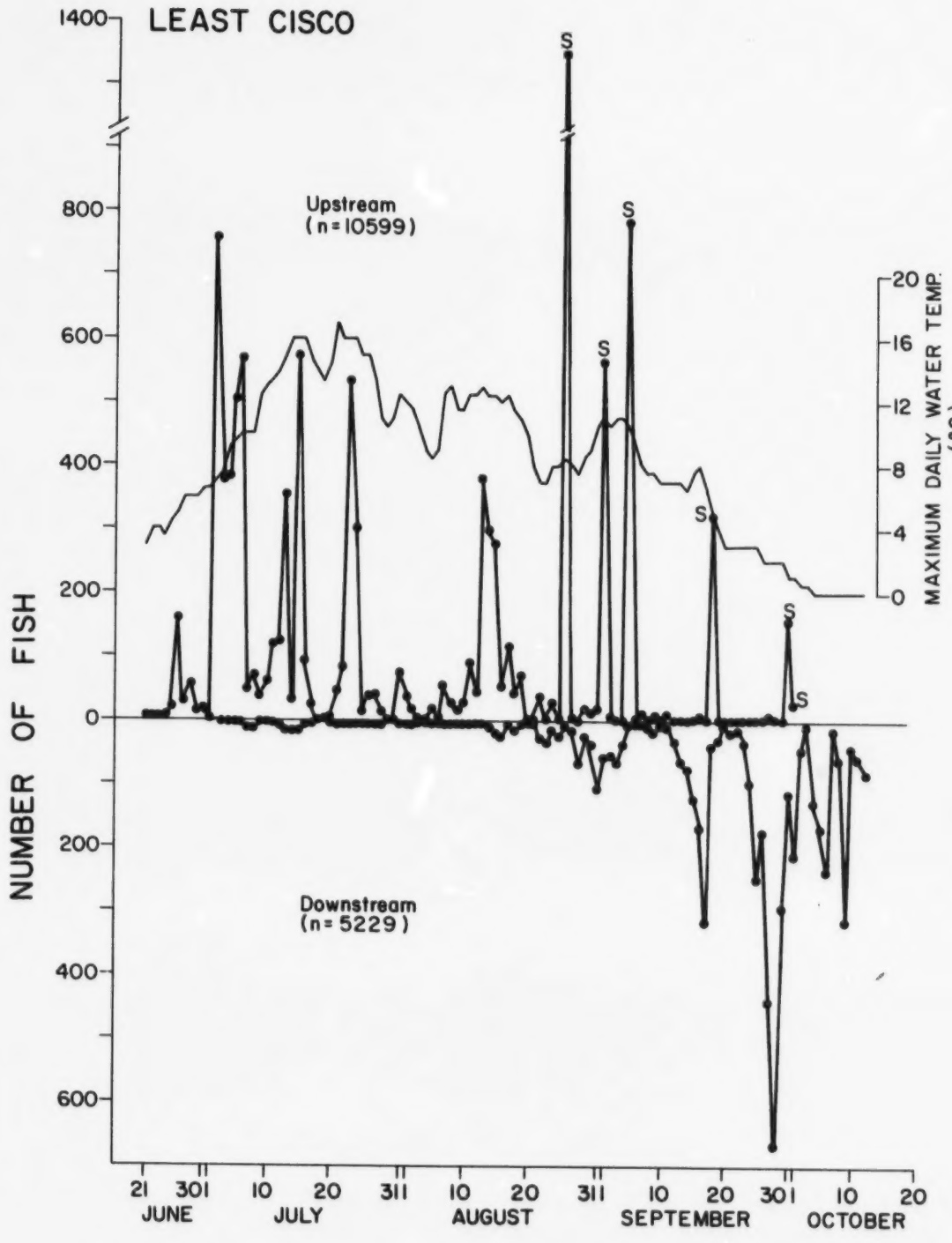

Fig. 26. Number of least cisco captured each day in upstream and downstream traps at Freshwater Creek, 1982. (S indicates that seined fish were included in daily total.)

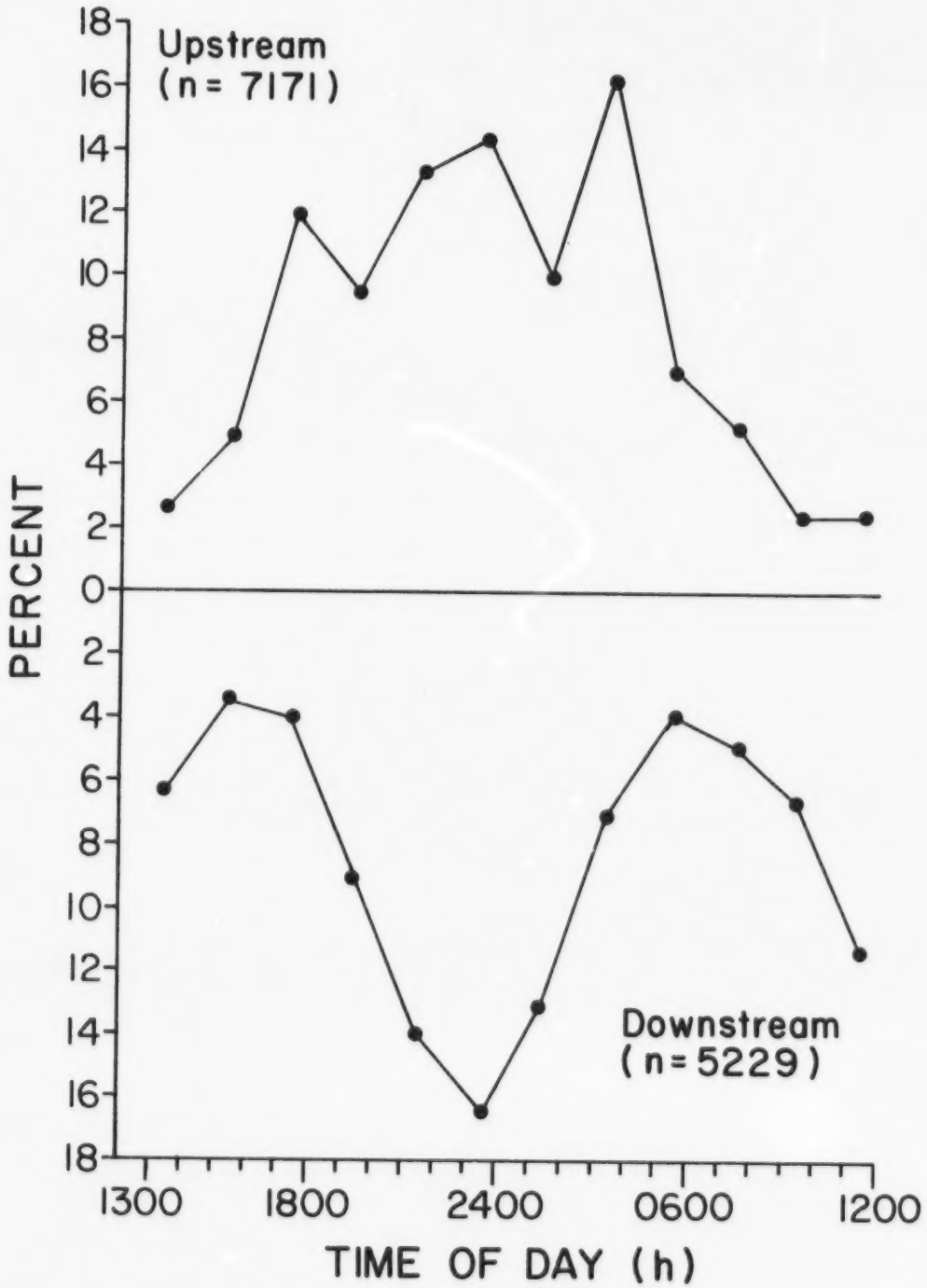

Fig. 27. Diel timing of the upstream and downstream migrations of least cisco in Freshwater Creek, 1982.

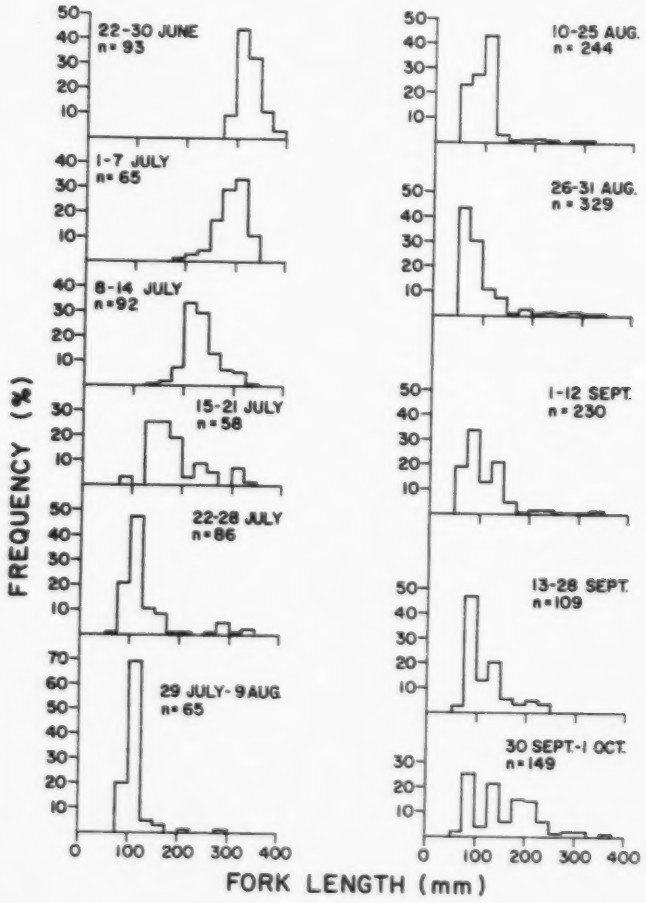

Fig. 28. Length-frequency distribution for least cisco measured during different segments of the upstream migration in Freshwater Creek, 1982.

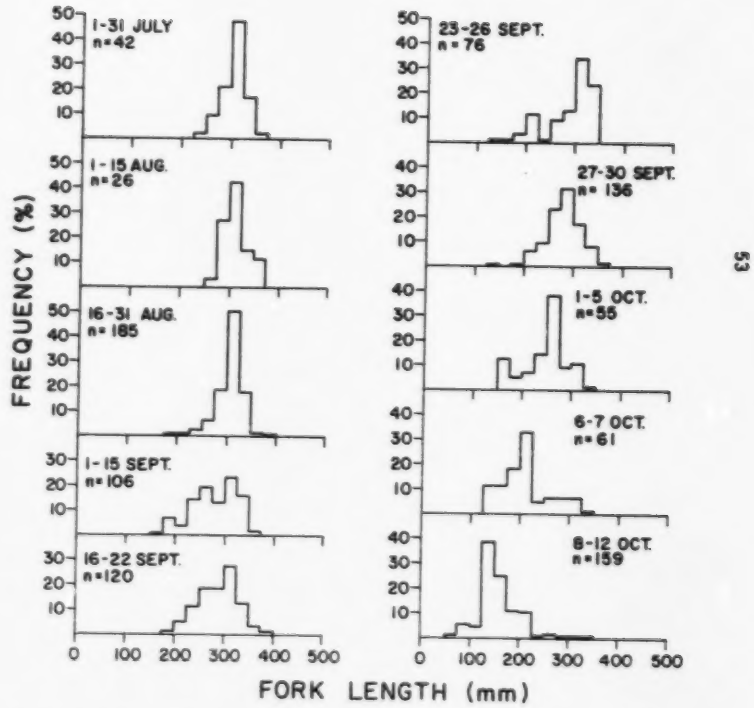

Fig. 29. Length-frequency distribution for least cisco measured during different segments of the downstream migration in Freshwater Creek, 1982.

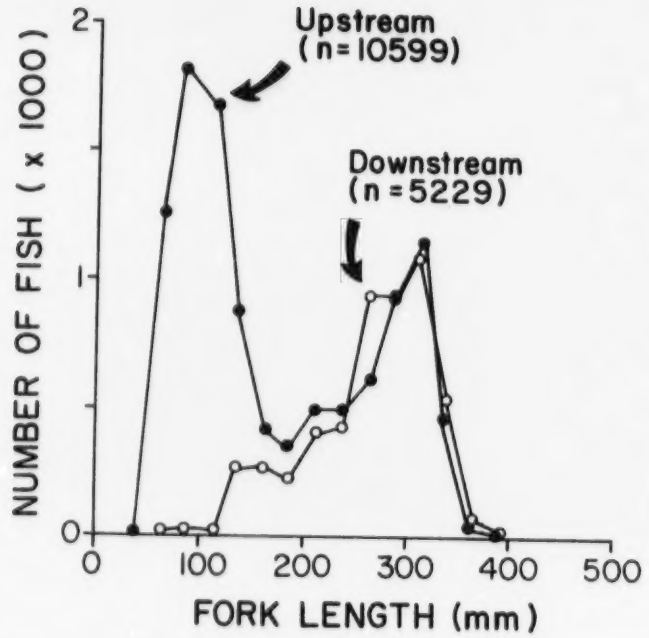

Fig. 30. Estimated overall length-frequency distributions for least cisco in the upstream and downstream migrations in Freshwater Creek, 1982.

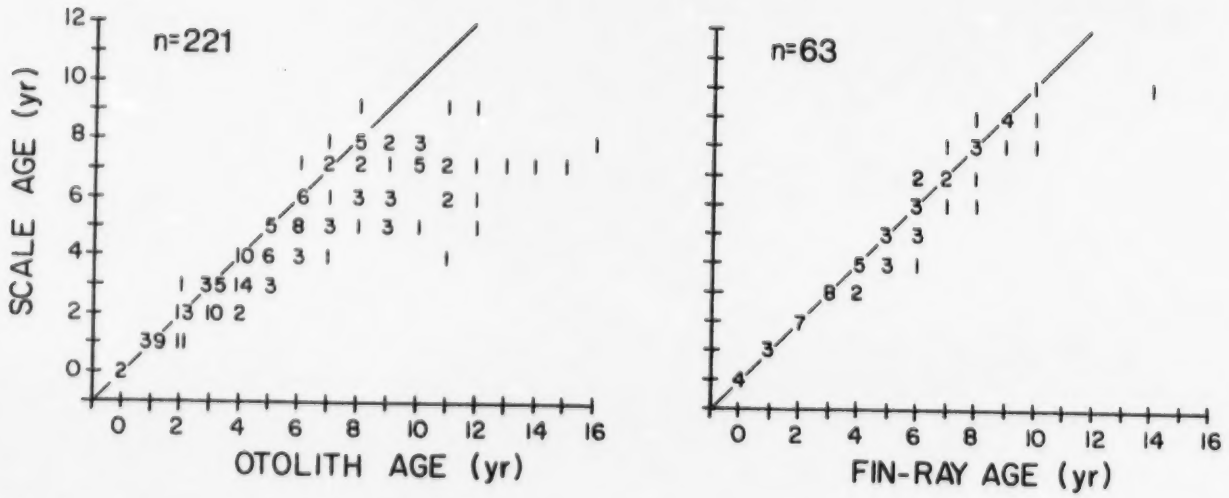

Fig. 31. Comparison of scale age:otolith age and scale age:fin-ray age pairs for least cisco from Freshwater Creek. (Scale age:otolith comparison includes Mayogiak Creek data from Bond and Erickson (1982).

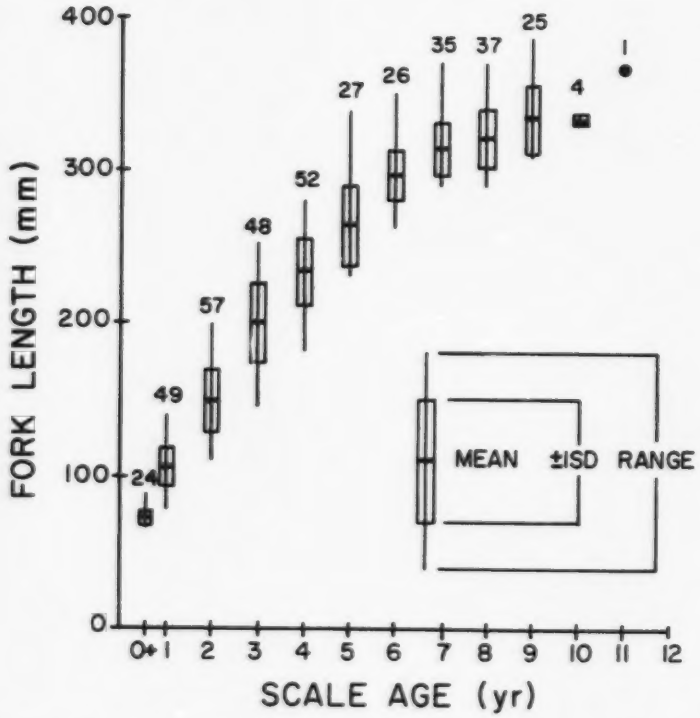

Fig. 32. Growth in fork length for least cisco captured in Freshwater Creek, 1982.

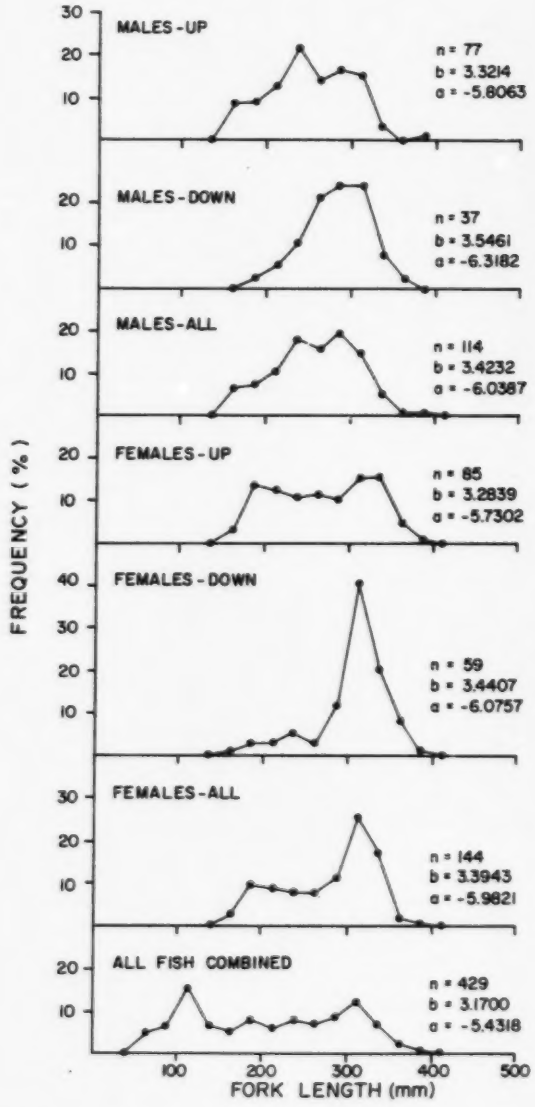

Fig. 33. Length-frequency distributions for samples of least cisco used in length-weight regression analysis, Freshwater Creek, 1982

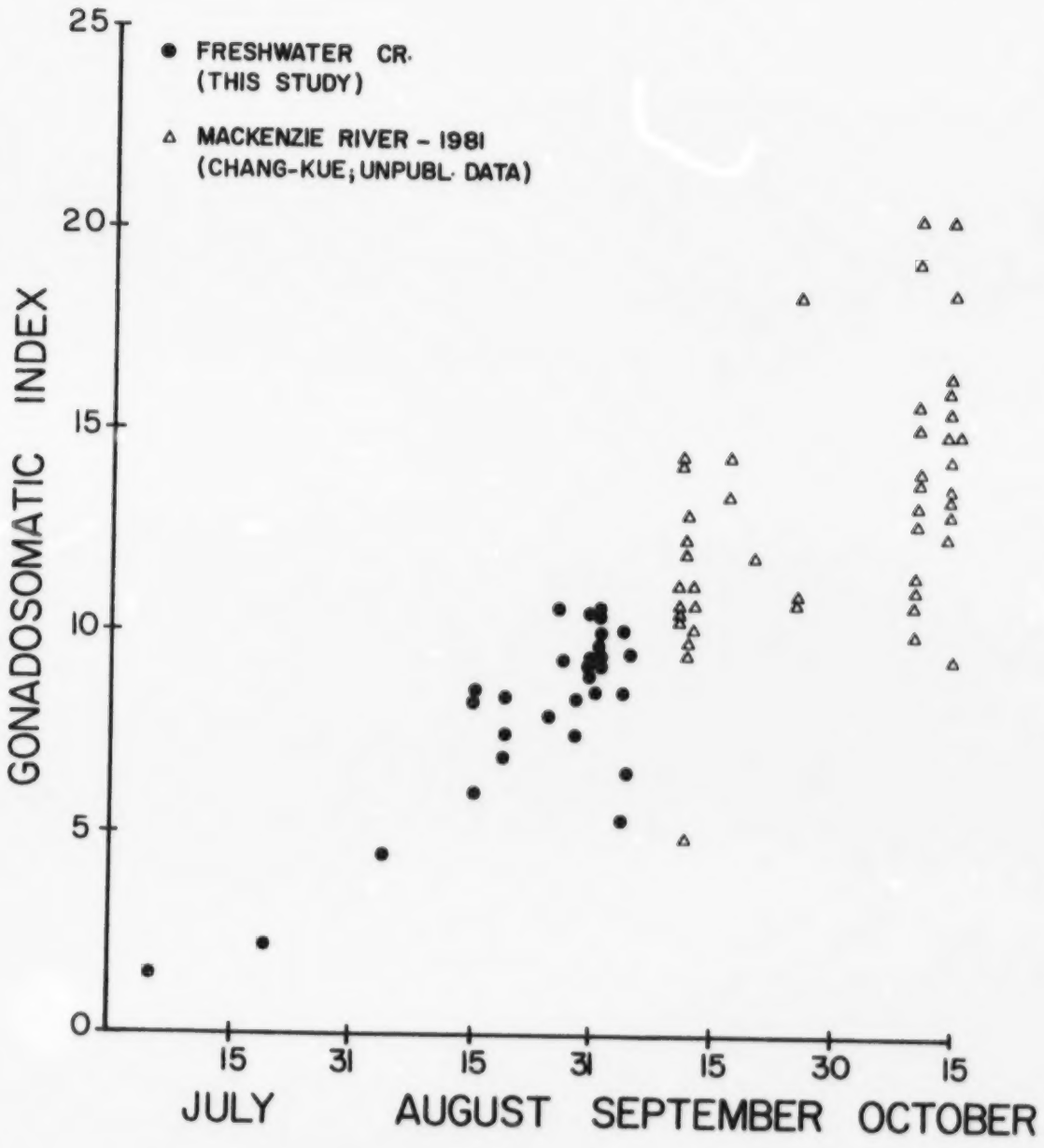

Fig. 34. Gonadosomatic index values recorded for mature female least cisco in Freshwater Creek, 1982 and in the Mackenzie River.

Table A1.1. Benthic macroinvertebrates identified from lakes of the Mayogiak and Freshwater Creek watersheds, 1981-1982.

Taxa	Mayogiak	Freshwater
Diptera		
Chironomidae		
Chironominae		
Stictochironomus sp.	+	+
Phaenopsectra sp.	+	+
Chironomus sp.	+	+
Xenochironomus sp.		+
Cryptochironomus sp.		+
Paratanytarsus sp.		+
Corynocera sp.		+
Tanytarsus sp.		+
Tanypodinae		
Procladius sp.	+	+
Ablabesmyia sp.		+
Diamesinae		
Potthastia sp.		+
Orthocladinae	+	+
Culicidae		+ [1]
Empididae		+
Simuliidae		+
Ephemeroptera		
Baetis sp.		+
Trichoptera		
Limnephilidae		+
Plecoptera		+
Mollusca		
Valvatidae		
Valvata sincera helicoidea	+	+
Lymnaeidae		
Lymnaea palustris	+ [1]	+
Sphaeriidae		
Sphaerium sp.	+	+
Crustacea		
Amphipoda		
Gammarus lacustris	+	+
Notostroca		
Lepidurus sp.	+ [1]	+ [1]
Ostracoda	+ [1]	
Oligochaeta	+	+
Hirudinea	+	+
Nematoda	+	+
Acarina		+

[1] Found in stomachs of fish captured in lakes. Not taken in dredge samples.

Table A2.1. Daily fence counts for broad whitefish (BWF), lake whitefish (LWF), and least cisco (LC) at Freshwater Creek, 1982.

Date	Number of Fish					
	Upstream			Downstream		
	BWF	LWF	LC	BWF	LWF	LC
June 21	1 984	781	6			
22	5 466	1 339	6			
23	4 866	1 058	4			
24	2 849	691	9			
25	3 259	416	20			
26	4 317	447	160			
27	3 847	597	30			
28	1 854	293	55	4		
29	1 066	88	12			
30	302	42	17			
July 1	53	1	2	1	-	-
2	11 114	459	754	19	1	-
3	3 748	453	377	24	2	4
4	3 376	422	382	379	-	3
5	6 545	648	507	339	5	1
6	4 741	423	564	191	2	3
7	566	83	50	354	-	14
8	1 134	119	69	691	3	11
9	1 194	86	38	10	-	-
10	434	90	64	15	-	1
11	575	92	117	65	-	3
12	555	93	122	198	5	9
13	1 432	222	355	342	7	15
14	198	34	34	654	17	15
15	1 467	177	573	392	28	13
16	373	83	96	281	5	7
17	131	36	24	95	4	3
18	100	21	-	110	3	1
19	136	27	2	110	7	1
20	627	50	7	138	14	3
21	918	18	48	457	56	6
22	1 213	22	84	146	21	2
23	1 032	50	531	163	37	8
24	628	26	301	205	74	2
25	142	13	15	161	82	1
26	192	4	38	312	143	-
27	196	11	41	7	9	-
28	93	5	13	158	103	-
29	21	4	-	244	97	-
30	28	5	-	66	23	-
31	954	18	75	374	69	-
Aug. 1	359	14	37	148	69	2
2	722	2	16	522	114	2
3	345	10	5	55	13	-
4	82	-	1	338	71	-
5	276	2	14	249	45	-
6	286	3	5	1 131	234	-
7	1 553	15	52	395	107	4
8	1 450	27	29	558	42	4
9	1 512	1	18	284	56	1
10	1 139	-	30	96	64	-
11	1 233	3	88	82	56	2
12	314	1	47	34	38	1
13	1 200	1	370	85	142	2
14	1 584	1	297	227	240	10
15	1 668	-	269	236	152	20
16	643	-	57	119	79	25
17	1 715	-	116	125	88	5
18	998	-	46	138	163	15
19	1 379	-	68	167	218	4
20	82	-	4	17	56	5

Table A2.1. cont'd

Aug. 21	113	4	2	31	34	3
22	595	1	36	157	54	29
23	140	0	4	721	138	35
24	314	1	28	618	82	15
25	201	-	5	245	86	26
26	2 109	19	1 353	88	6	8
27	65	-	7	2 563	84	18
28	152	-	-	4 996	561	68
29	575	1	19	1 032	64	25
30	407	-	12	1 357	203	38
31	476	12	19	1 880	385	108
Sept. 1	694	1	569	3 214	282	58
2	78	-	7	1 692	172	54
3	75	1	2	4 050	966	67
4	21	-	-	859	220	35
5	362	9	786	353	83	8
6	31	-	5	663	252	7
7	121	-	10	479	271	6
8	6	-	1	376	237	11
9	49	-	8	293	122	20
10	70	-	3	358	312	10
11	249	-	9	312	184	11
12	47	-	2	682	431	31
13	5	-	-	5 229	640	66
14	2	-	-	4 875	1 156	77
15	1	-	-	5 593	673	121
16	80	-	6	4 180	1 407	167
17	9	-	1	3 538	1 764	315
18	248	3	325	215	279	40
19	1	1	-	93	192	30
20	1	-	-	47	78	10
21	36	-	1	358	159	21
22	6	-	2	112	80	14
23	67	-	-	842	111	35
24	108	2	4	1 067	239	94
25	35	-	1	6 248	801	245
26	80	-	3	4 460	749	178
27	31	-	7	9 591	1 500	440
28	11	-	2	7 522	1 476	668
29	0	-	-	3 183	887	298
30	192	-	160	1 026	628	115
Oct. 1	49	-	29	1 489	535	210
2	TRAP REMOVED			600	125	48
3				304	19	10
4				2 255	227	130
5				1 750	329	168
6				1 298	147	238
7				99	18	13
8				80	20	61
9				150	11	312
10				99	22	45
11				53	9	59
12				63	7	82
Total	100 178	9 684	10 599	105 149	22 382	5 229

Table A3.1. Detailed food habits of broad whitefish captured in the Freshwater Creek watershed, 1982. Results are expressed as frequencey of occurence (FO), percentage composition by number (% N), and estimated composition by volume (% Vol.).

Food Item	Fence Site						Lakes - Summer						Lakes - Winter					
	Upstream			Downstream			Lake 6			Lake 8			Lake 8			Lake 3		
	FO	% N	% Vol.	FO	% N	% Vol.	FO	% N	% Vol.	FO	% N	% Vol.	FO	% N	% Vol.	FO	% N.	% Vol.
Diptera																		
Chironomidae																		
Chironominae larvae				25.7	4.9	2.5	25.0	12.2	15.6									
Orthocladinae larvae				2.8	20.9	3.2												
Orthocladinae pupae				2.8	0.1	0.6												
Tanypodinae larvae				17.1	1.8	1.9	100.0	17.8	9.4							100.0	4.2	2.1
Unid. larvae	50.0	52.0	20.0	65.7	16.9	3.8	50.0	40.3	18.8	60.0	2.3	4.9	100.0	3.6	13.3	100.0	60.5	25.5
Unid. pupae				2.8	0.1	1.3				20.0	0.1	2.4						
Simuliidae larvae	25.0	20.0	10.0	2.8	0.1	0.6												
Unid. larvae				5.7	0.1	1.9												
Unid. pupae				8.6	0.7	2.5				20.0	0.1	2.4						
Unid. adult	25.0	4.0	10.0															
Plecoptera																		
Nemouridae																		
Nemoura sp. (nymph)				2.8	<0.1	0.6												
Trichoptera																		
Phryganeidae																		
Ptilostomis sp. (adult)				5.7	0.1	1.9												
Unid. larvae				17.1	0.5	3.2				20.0	0.1	4.9				66.7	2.0	6.4
Coleoptera																		
Unid. larvae				2.8	<0.1	0.6												
Unid. adults				2.8	<0.1	1.3												
Mollusca																		
Valvata sincera helicoidea	25.0	20.0	10.0	77.1	13.8	5.1	50.0	7.4	12.5	100.0	83.5	24.4	66.7	93.2	26.7	66.7	20.6	19.1
Lymnaea palustris				22.8	1.1	6.3				60.0	1.2	7.3	66.7	1.2	6.7			
Sphaeriidae				80.0	35.0	6.3	50.0	22.3	15.6	80.0	3.4	9.8	33.3	1.2	6.7	83.3	12.7	12.8
Unidentified				5.7	0.2	3.2												
Crustacea																		
Amphipoda																		
Gammarus lacustris				17.1	0.9	3.2				60.0	9.2	19.5	33.3	0.3	6.7			
Nematoda	25.0	4.0	10.0	20.0	2.9	0.6							33.3	0.3	6.7			
Oligochaeta													33.3	0.3	6.7			
Digested material, debris	50.0		40.0	97.1		48.1	100.0		28.1	100.0		24.4			26.7	83.3		34.0
Number stomachs examined	6			46			4			5			4			6		
Number stomachs empty (%)	2 (33.3)			11 (23.9)			0 (0)			0 (0)			1 (25.0)			0 (0)		
Total food points assigned (%)	10 (8.3)			158 (17.2)			32 (40.0)			41 (41.0)			15 (18.8)			47 (39.2)		
Total food points unassigned (%)	110 (91.7)			762 (82.8)			48 (60.0)			59 (59.0)			65 (81.2)			73 (60.8)		

Table A4.1. Detailed food habits of lake whitefish captured in the Freshwater Creek watershed, 1982. Results are expressed as frequencey of occurence (FO), percentage composition by number (% N), and estimated composition by volume (% Vol.).

Food Item	Fence Site						Lake 8					
	Upstream			Downstream			Summer			Winter		
	FO	% N	% Vol.	FO	% N	% Vol.	FO	% N	% Vol.	FO	% N	% Vol.
Diptera												
Chironomidae												
Chironominae larvae	50.0	15.8	8.7	6.7	<0.1	1.0	50.0	3.0	6.2			
Tanypodinae larvae	4.2	0.1	1.0	13.3	0.1	1.0						
Unid. larvae	37.5	3.7	1.9	6.7	<0.1	0.1						
Unid. pupae				6.7	0.1	1.0						
Simuliidae larvae	8.3	6.4	2.9									
Unid. larvae	12.5	0.6	4.8									
Unid. pupae				6.7	0.1	1.0						
Unid. adult	4.2	0.1	1.0									
Plecoptera												
Nemouridae												
Nemoura sp. (nymph)	29.2	1.3	2.9									
Unid. nymphs	4.2	0.3	1.9	13.3	0.1	1.0						
Trichoptera												
Phryganeidae												
Ptilostomis sp. (larvae)	8.3	0.7	3.9									
Limnephilidae												
Onocosmoecus sp. (larvae)	4.2	0.1	2.9									
Unid. larvae				6.7	<0.1	2.1						
Unid. larvae	16.7	1.2	4.8	6.7	0.1	2.1						
Mollusca												
Valvata sincera helicoidea	25.0	6.1	4.8	86.7	34.6	19.6	100.0	8.9	6.2	100.0	100.0	60.0
Lymnaea palustris	12.5	0.6	3.9	33.3	1.7	8.2	50.0	32.6	31.2			
Sphaeriidae	29.2	2.4	2.9	60.0	2.6	5.2	100.0	20.7	12.5			
Crustacea												
Amphipoda												
Gammarus lacustris	12.5	0.6	3.9	26.7	4.2	15.5	100.0	34.8	18.8			
Cladocera	8.3	8.9	1.0	6.7	0.1	1.0						
Copepoda	4.2	48.8	3.9	13.3	6.6	2.1						
Ostracoda				33.3	47.7	4.1						
Nematoda	4.2	0.1	1.0	13.3	0.1	1.0						
Acarina	25.0	1.2	1.0	66.7	2.0	2.1						
Fish (Pungitius)	8.3	1.2	11.7									
Digested material, debris	70.8		29.1	100.0		30.9	100.0		25.0	50.0		40.0
Number stomachs examined		29			18			2			2	
Number stomachs empty (%)		5 (17.2)			3 (16.7)			0 (0)			0 (0)	
Total food points assigned (%)		103 (17.8)			97 (26.9)			16 (40.0)			5 (12.5)	
Total food points unassigned (%)		477 (82.2)			263 (73.1)			24 (60.0)			35 (87.5)	

POOR

QUALITY

ORIGINAL